New Scientist

2024 IN REVIEW

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Did AI lose its shine?
Incredible northern lights
Pig kidney transplant hope
...and yes, climate change

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BUMPER QUIZ OF THE YEAR

14/21 December 2024

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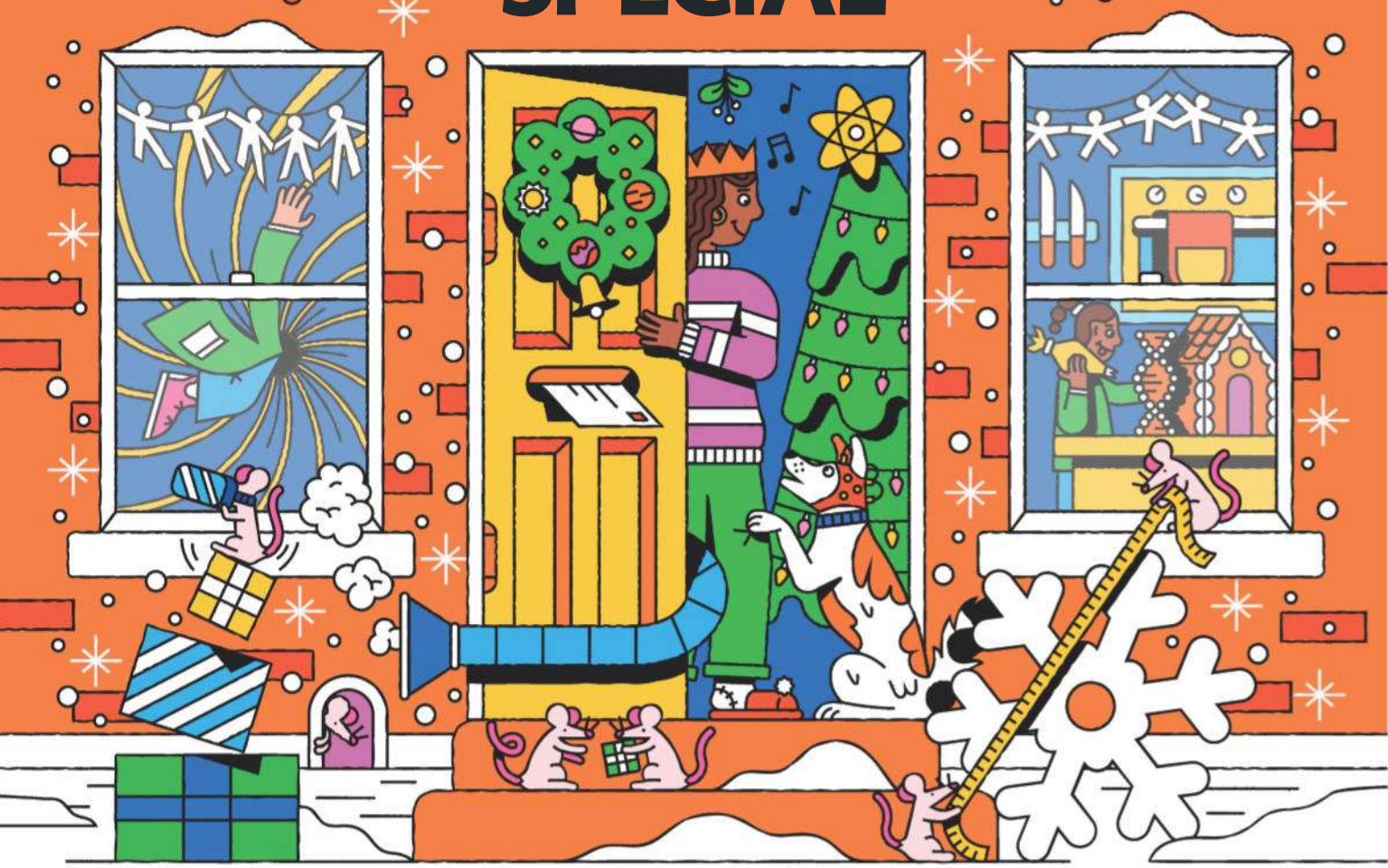

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This week's issue

Christmas & New Year special

Vol 264 No 3521/22
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Dear reader,
Welcome to our annual bumper holiday issue, packed full of festive fun. This year we put canine cognition to the test, search for the ultimate children's gift (as determined by science, of course) and attempt to make the world's largest snowflake. We also have our review of the year, original science fiction by bestselling author Nnedi Okorafor, a gargantuan word search, the best ever gingerbread recipe and a lot more to keep you entertained through the festive period. Wishing you a very happy holiday.

Catherine de Lange
New Scientist editor

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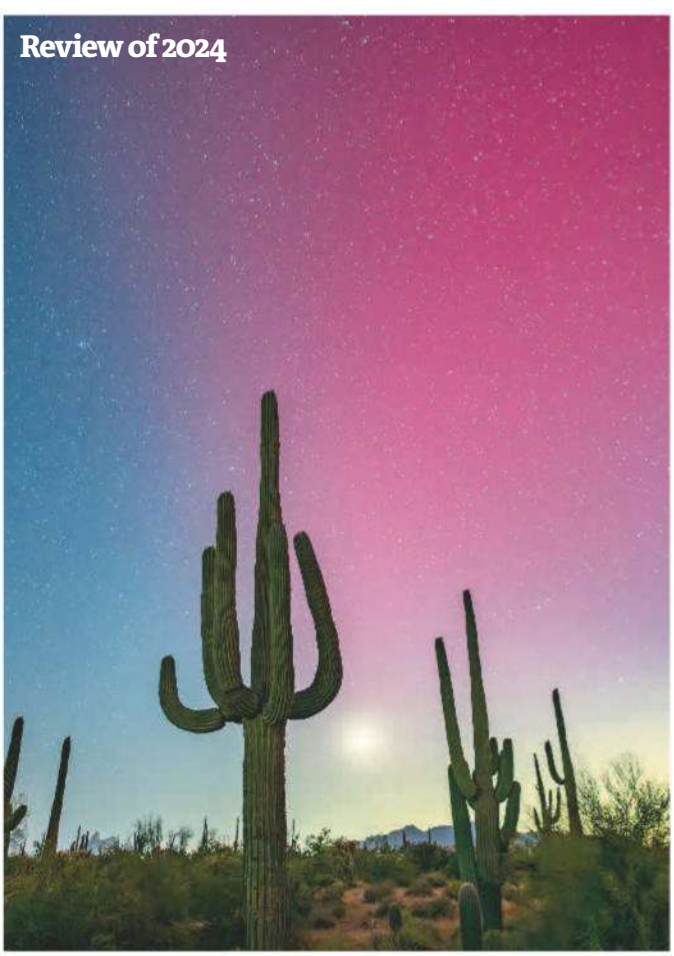

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How to live a long and healthy life

There is an explosion of research into longevity and human well-being, with groups such as the Human Flourishing Program at Harvard University leading the way. But how much can we really affect our lifespan? Are longevity advocates selling snake oil or are there genuine interventions that will help us to live longer? And can science really help you live a happier, more fulfilled life? Join six world-leading experts on 8 February at London's Congress Centre to find out.

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Podcast

Weekly

The team discuss a new kind of brain implant made with living brain cells, while Bethan Ackerley, *New Scientist*'s resident culture critic, gives the lowdown on the best science fiction TV and film of the year. Plus, there is a special report on Antarctica from our Australia reporter, James Woodford, who went to an emergency summit on the continent's future attended by 500 scientists.

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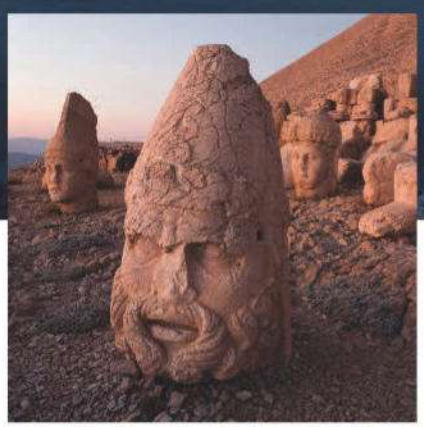

Megalithic Malta: Temples, architecture and archaeology

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Discover the captivating islands of Malta and Gozo, each brimming with extraordinary history and archaeological treasures. These islands are home to a wealth of remarkable sites, from the ancient, enigmatic temples to the impressive fortifications built by the Knights of St. John.

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- Discover Ġgantija, the second oldest human-built freestanding structure in the world
- Enjoy talks and walking seminars from award-winning journalist Juliet Rix

The science of the Renaissance: Italy

7 April 2025 | 6 days

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- Visit the European Gravitational Observatory to see the Virgo interferometer, which is designed to detect gravitational waves and is the only one of its kind in Europe
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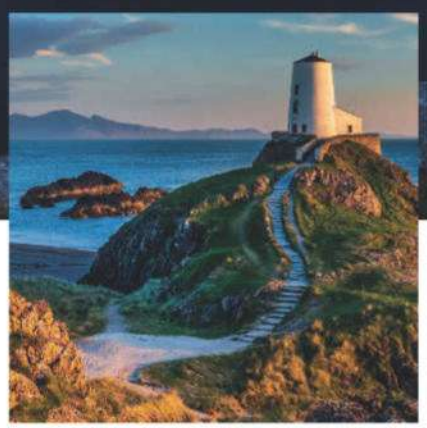
- Explore the remarkable collections, architecture and churches that showcase the growing knowledge of the era



Retracing Charles Darwin's travels across North Wales

5 May and 1 September 2025
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Explore the dramatic landscapes of Eryri (Snowdonia) National Park and examine the region's geology and how it has been transformed by volcanic and glacial activity over millions of years. Discover the story of Charles Darwin's 1831 and 1842 tours of Wales and retrace his travels on this tour.

- See the spectacular landscapes of north Wales, including the mountains of Snowdonia National Park, the tranquil Llyn Ogwen lake and the rugged coasts of Anglesey
- Discover the evidence that Darwin used to unravel the origin of these landscapes
- Visit the fascinating Parys Mountain, a huge source of copper that has been mined for 4000 years

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Pessimistic optimism

To reach ambitious goals, we can learn from those who prepare for the worst

REUTERS/TUANE FERNANDES

THIS year will be remembered for many pioneering events, from the first private landing on the moon (see page 19) to the first pig kidney transplants in living humans (see page 25). Unfortunately, another, darker first looms large over 2024: although the numbers won't be officially confirmed until next month, it is exceedingly likely that this year was the first to cross the totemic climate target of 1.5°C of global warming (see page 16).

Let's be clear on exactly what this means. It isn't a breach of the world's most important climate treaty, the 2015 Paris Agreement, in which nations pledged to limit long-term temperature rises to below 1.5°C, as this figure is generally considered to refer to a 20-year average. It also isn't a sign that the world is doomed and that we should give up all hope of combating climate change, because every fraction of a degree that we keep temperatures down will still improve the lives of billions of people versus not doing so. But it is, inarguably, a global failure that warming has hit this level, even if only for one year (so far).

Breaching 1.5°C also comes as the world enters a new, uncertain phase of climate change. As we have reported throughout the year, the extreme warming of 2024 (matched only by 2023) has seen scientists scrambling to understand what is going on, from growing concerns over changes in key ocean currents to unexplained levels of Antarctic sea ice loss.

Going into a new year with such uncertainty, it is hard not to feel pessimistic, but that might not be a bad thing. Next year will mark 10 years since the Paris Agreement came into force, and even at the time, it was clear the 1.5°C target was pushing at the limit of what was achievable. As we wrote in our end of year leader at the time:

"Pessimism doesn't make for good photo ops. It asks 'what if we fail?' and 'what if we are wrong?'"

"As a call to action, it is quixotic: its aspiration of a 1.5°C cap on global warming seems almost totally unachievable." Indeed, remaking the modern world to halt greenhouse gas emissions and reach net zero is the most ambitious goal humanity has ever set itself.

Such ambition is essential given the scale of the challenge facing us, yet it isn't enough. Setting ambitious, optimistic goals like the Paris Agreement is the easy part, where politicians get to line up in photos, smile and shake hands. It feels warm and fuzzy.

But to achieve such goals, pessimism must rule. Pessimism doesn't make for good photo ops. It asks "what if we fail?" and "what if we are wrong?" – questions that, if they are to be tackled, involve grappling with the deep uncertainties of our green transition, whether technological, social or economic. Doing otherwise is a recipe for failure.

There are lessons to be learned from 2024's successes. Space engineers and surgeons alike default to an assumption of error, given the complexities of landing on the moon or performing intricate operations. To mitigate against this, they use a simple tool: the humble checklist. By identifying points of failure and taking steps to avoid them, the odds of success become much greater.

It wouldn't make much sense to have a "climate checklist", given we are talking about an ongoing global process rather than a single operation or space mission, but the underlying ethos still applies. One big point of failure is the annual UN climate talks. At the 29th such COP summit, in Azerbaijan this year, the hosts praised fossil fuels as a "gift of God".

COP30, which is due to be held in Belém, Brazil, next November, offers an opportunity for an attitude reset. Brazilian President Luiz

Inácio Lula da Silva is already making noises in that direction, promising a "turnaround COP", but can he deliver? Perhaps the strongest message he could send would be to take to the stage and publicly admit the failure of the COP process to date, flanked by unsmiling world leaders with a clear plan to do better. Don't bet on Santa delivering that wish, though.

Some contrition and pessimism could also help with another problem that has been quietly bubbling up during 2024: the looming threat of a bird flu pandemic (see page 20). The H5N1 virus has spread through US dairy herds, with minimal efforts at surveillance and mitigation from US health officials. As a result, the number of human infections there has also grown, to more than 50 as we went to press.

The virus isn't yet well adapted to people and, so far, there has been no known human-to-human transmission, but each new infection increases the chances that a random mutation will change that. Optimistically rolling the dice and hoping for double sixes doesn't a good health policy make. In an ideal world, the US would already be planning for a possible pandemic, with fingers crossed that it never comes to pass. With the incoming president, Donald Trump, favouring the vaccine sceptic Robert F. Kennedy Jr as the secretary of health and human services, we don't live in an ideal world, meaning that other countries should be making their own plans. This is the only rational response to uncertainty.

Clearly, all this pessimism isn't particularly in the holiday spirit. Be assured, however, that throughout this double issue of *New Scientist* lies a world of festive treats, from the science of believing in Santa (see page 10) to the quest for the world's largest snowflake (see page 64).

As for next year, raise a glass – both half-empty and half-full – to the researchers and companies developing new ways to tackle climate change, be it sucking carbon dioxide from the air or genetically remaking our food to be greener (of which you can read more in our 2025 preview next issue), and hope that the uncertainty thrown up by this year's climate news can, and will, be a catalyst for change. ▮

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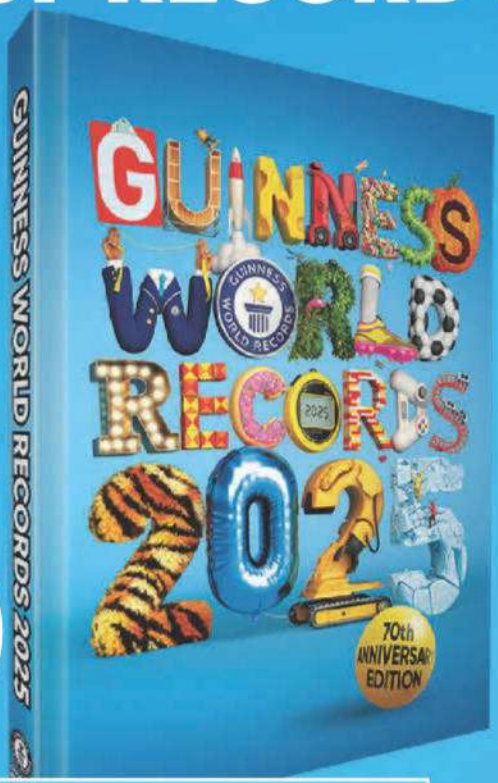

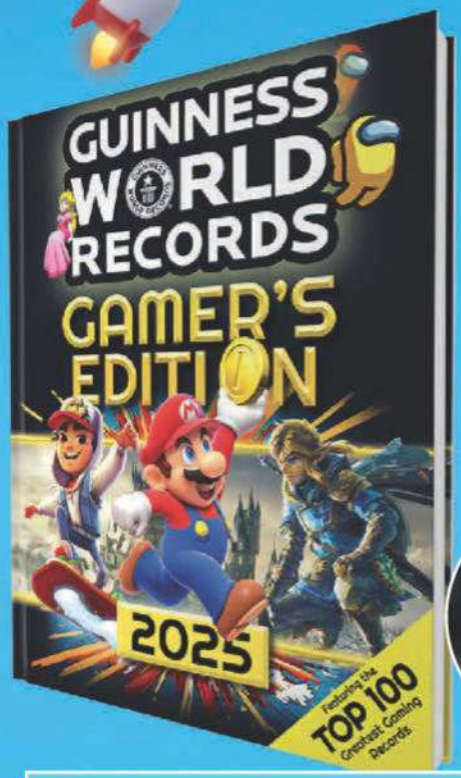

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News

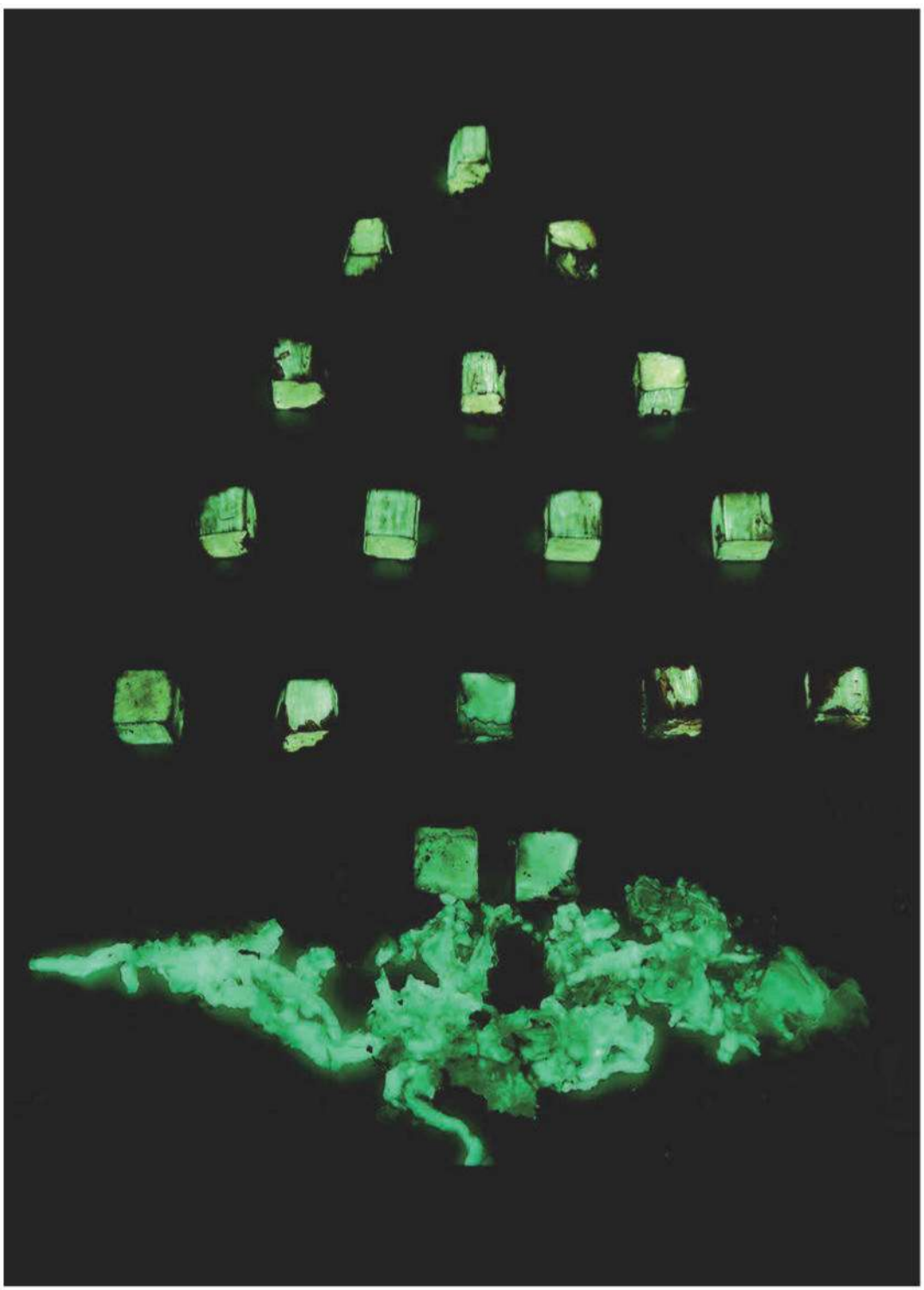
Ready for take-off
Flying robot leaps upwards then takes to the air like a bird **p9**

A liver, not a hater
Mesopotamians felt happiness in their livers **p11**

Deep insights
What stalagmites can tell us about life on a hotter Earth **p12**

Digital doctor tested
Chatbot gives medical advice to hundreds of people **p14**

That mushy feeling
A good crop of fungi makes plants more attractive to bees **p15**



EMPA

Materials science

Glowing with festive cheer

This glow-in-the-dark Christmas tree is made from chunks of balsa wood impregnated with the bioluminescent ringless honey fungus (*Desarmillaria tabescens*). When the wood is exposed to air, an enzyme reaction produces the light-emitting compound luciferin. The effect lasts for about 10 days (*Advanced Science*, doi.org/nwgb). Such hybrid living material may lead to eco-friendly home lighting.

Mathematics

A surprising twist on infinity

Maths contains an entire ladder of infinities, but a discovery threatens to upset that order and perhaps redefine the structure of the mathematical universe, finds **Alex Wilkins**

A NEW kind of infinity appears to break the rules of how extremely large numbers behave, and could redraw the way the mathematical universe is ordered.

It may come as a surprise, but mathematicians have long known that there is more than one kind of infinity. In 1878, Georg Cantor first showed that the infinite set of real numbers, which includes negatives and decimals, is actually larger than the infinite set of natural, or whole, numbers. Proving this involves a careful comparison between the two sets, rather than attempting the impossible task of counting them all.

Following Cantor's ideas, mathematicians soon realised that they could construct ever-larger infinite sets, creating a hierarchical ladder of sets that is itself infinite.

"People have been coming up with larger and larger notions of infinity," says Juan Aguilera at the Vienna University of Technology in Austria. "You can look at all the previous ones that people have come up with and you can fit them in a hierarchy."

Now, Aguilera and his colleagues have proposed two new sizes of infinity, called exacting and ultra-exacting cardinals, that don't obey the rules (arXiv, doi.org/nv49). "They don't quite fit in this linear hierarchy," says Aguilera. "They interact very, very strangely with other notions of infinity."

Aguilera and his team defined these sets by making them so large that they must contain mathematically exact copies of their entire structure – a bit like a house that contains multiple, full-scale models of itself – and also accommodate small versions of larger sets, like adding models of the surrounding neighbourhood or city to the house. Ultra-exacting cardinals have one further rule, which says that these sets must also contain the mathematical rules of how to make them – as if the nested house was also wallpapered with blueprints of itself.

"These new sets have unusual properties that play havoc with some of the deepest rules of maths"

These unusual properties are what cause these sets to fall off the infinity ladder, as they play havoc with some of the deepest rules of maths, which spring from around the beginning of the 20th century. This is when mathematicians began trying to find a rigorous foundation for their entire field. They defined a basic set of rules, or axioms, that could be used to build and prove any other theory. The most widely accepted form of this foundation today, known as Zermelo-Fraenkel set theory, included a controversial rule called the axiom of choice that is at the root of the problem.

This axiom says that you can always build a new set of numbers by picking out those from other sets, but doesn't tell you explicitly how to do it. Some mathematicians felt that this didn't work when considering infinite sets, because it would require asserting the existence of mathematical objects without offering a way to prove them. However, over time, they came to accept the rule, and it is now used as a key measuring stick in organising the infinite ladder, carving it into three broad regions.

At the bottom of the ladder, the first and smallest region contains infinities that adhere to the set theory axioms – these are the real and natural number infinities studied by Cantor. At the top, the third and largest region has numbers so huge that all set theory axioms break down, including the axiom of choice. It is a region of "chaos", says Aguilera.

Many infinities fit somewhere between these, in a second region. Exacting and ultra-exacting cardinals initially appeared to as well – but when the researchers actually tried to pin them down, they found that it wasn't possible. "It's not quite clear if they are at the top of this middle region, where the axioms are still compatible with all the other axioms of set theory, or whether they are forming a fourth region that is kind of to the side of the chaotic region, but on top of the previous ones," says Aguilera.

Infinity is even more complex than you might think

ANDRIY ONUFRIYENKO/GETTY IMAGES

Staking the universe

Resolving the question of where these new sets fit is more than just academic tidiness, however – the entire mathematical universe could be at stake. This is because of a key unsolved problem called the Hereditarily Ordinal Definable (HOD) conjecture, which proposes that as you get to the very largest infinities, the axiom of choice starts to make sense instead of leading to contradictions. This would suggest that mathematics becomes more ordered at the largest scales, says Gabriel Goldberg at the University of California, Berkeley, who wasn't involved in the work. "The large cardinals are sort of justifying the axiom of choice for you."

If these exacting cardinals are accepted by the wider mathematical community – which isn't necessarily certain, given their existence straddles the borders of maths and philosophy – then "it strongly suggests that maybe the HOD conjecture is false, so maybe chaos rules", says team member Philipp Lücke at the University of Hamburg, Germany.

Or perhaps not. "It's a little too early to say that that's the picture," says Goldberg, who thinks order may yet win out. "It seems like actually there's a lot of structure that emerges."

Biology

New forms of animals made by fusing several comb jellies together

Michael Le Page

FRANCO BANFI/BIOSPHOTO/ALAMY

***Mnemiopsis leidyi* is a jellyfish-like animal native to Atlantic waters**

IT MAY be the closest scientists have yet come to creating Frankenstein's monster. Living pieces of dozens of individual animals known as comb jellies have been fused together to create an array of new forms that, in some cases, survived for more than a week.

These chimeric animals are more than just physically connected bits of different individuals, says Leonid Moroz at the University of Florida. Their nervous systems also fuse together, creating entities that he and his colleague Tigran Norekian, also at the University of Florida, call neurobots. "We were able to directly prove that the neural system fused," he says.

This kind of experiment offers unprecedented opportunities for synthetic biology, says Moroz. The researchers' aim is to improve our understanding of biology to the point where we can grow tissues and organs for treating various diseases.

"If you are a good engineer, you can eventually make a bridge or airplane," says Moroz. "Biology is much more complicated."

The team's work was inspired by a recent study by Kei Jokura, now at the National Institute for Basic Biology in Japan, and his colleagues. When Jokura was studying a species of comb jelly, or ctenophore, called *Mnemiopsis leidyi*, he noticed a strange animal that seemed to consist of two fused individuals.

Further experiments showed that when pairs of injured individuals were put together, they fused with each other nine times out of 10.

"They took the part of one comb jelly that contains its primitive brain and put it in another one"

Moroz and Norekian have now gone further, fusing various parts of individual ctenophores together. For instance, they took the part of a comb jelly that contains its primitive brain from one individual and used it to replace that part in another – the ctenophore equivalent of a head transplant. "Virtually all possible combinations were able to produce [moving] animals," says Moroz.

By using a stain that binds to a component in neurons, the pair confirmed that nerve cells grew connections across the fusion scar and connected the neural networks of different individuals (bioRxiv, doi.org/nv4j).

The researchers have also combined parts from more than two individuals. Moroz says they have now fused "many dozen" into single entities.

Moroz and Norekian have also shown that this fusion works in two other species of ctenophores, *Bolinopsis microptera* and *Pleurobrachia bachei*. They are now testing whether a part of one species can be fused with a part from another species.

Parts of other kinds of animals can't usually be fused together because their immune system will attack "non-self" cells – this is why organ transplants usually require immune suppression. But ctenophores branched off from other animals very early on, and it appears their immune systems never evolved the ability to distinguish self from non-self.

"I'm thrilled to hear that our work has inspired further research," says Jokura, adding that he is excited to learn about the potential for fusing across species as well as individuals.

A lot of biological research is subtractive, says Jokura: genes are disabled to see what happens. With this kind of fusion, it is possible to do additive research, he says, to see how things work when put together.

"Fusion experiments could provide an entirely new lens through which to study physiological phenomena and may indeed lead to innovative approaches in synthetic biology," says Jokura. ▮

Technology

Flying robot leaps upwards then takes to the air like a bird

Alex Wilkins

A ROBOT that can jump into flight like a bird could eliminate the need for small fixed-winged drones to take off from runways.

Birds use the powerful explosive force generated by their legs to leap into the air and start flying, but building a robot that can withstand the strong acceleration and forces involved in doing that has proved difficult.

Now, Won Dong Shin at the Swiss Federal Technology Institute of Lausanne and his colleagues have built a flying propellered robot called RAVEN that can walk, hop and jump into the air to start flying, with legs that work like a bird's.

Unlike real birds' legs, which have joints at the hip, knee and ankle, RAVEN's legs have just two joints, at the hip and knee, that are powered by motors. There is also a spring in each foot that can store and release elastic energy. Using fewer components meant that Shin and his team could keep RAVEN to a weight of around 600 grams, similar to that of a crow.

In indoor tests, RAVEN could jump almost half a metre into the air and at 2.4 metres per second – which is a similar speed to birds of the same size – at which point a propeller takes over (*Nature*, doi.org/nv4w). Being able to launch upwards from anywhere could make RAVEN useful in disaster relief missions where regular fixed-wing drones can't land or take off, says Shin. ▮

The RAVEN robot has springs in its feet, which help it take off

2024 EPFL/ALAIN HERZOG

Psychology

Does Santa change child behaviour?

You might expect a child's belief in Father Christmas – with his ability to know if kids have been good – would affect the way they act. But other festive rituals may play a bigger role, says **Michael Marshall**

HE'S making a list, he's checking it twice, but Santa's festive surveillance seemingly does nothing to improve children's behaviour. Instead, it may be that wider Christmas rituals, like putting up a tree and going carolling, can prompt children to be a bit nicer – a finding that may help us better understand how religion influences behaviour.

"The question was, does belief in Santa Claus influence how children behave?" says Rohan Kapitány at Durham University in the UK. "Does this belief, or anything about Christmas, actually make children behave nicely and not naughty?"

To find out, Kapitány and his colleagues ran a preliminary study over Christmas 2019. They skipped 2020 due to the covid-19 pandemic, but ran larger follow-ups in 2021 and 2022. In total, they recruited more than 400 people in the UK with children aged 4 to 9.

Like Santa, the team checked their work twice, interviewing parents once several weeks before Christmas and once in the week before Christmas Day. Each time, they asked the parents questions about their Christmas-related behaviours and their own feelings about the holiday, as well as about their children's belief in Santa. They also asked about three kinds of behaviour: prompted ("my child shared their toys after being prompted"), unprompted ("my child helped with household tasks without being prompted") and deviant ("my child has lied").

According to the parents' reports, there was no significant change in children's overall behaviour between the two times (OSF Preprints, doi.org/nwf3).

"They don't find evidence that kids are just behaving better as they approach Christmas time," says Jane Risen at the University of Chicago, who wasn't involved in the work. That is despite many parents saying they use Christmas as a tool to encourage prosocial behaviour – such as acts of kindness – with promises of presents for good girls and boys.

TRISTAN FEWINGS/GETTY IMAGES FOR HAMLEYS

Belief in Santa Claus alone isn't enough for a happy Christmas, but rituals like decorating trees (below) help encourage good behaviour

"Many parents say they use Christmas as a tool to encourage good behaviour"

ANNA PEKUNOVA/GETTY IMAGES

However, Kapitány's team did find a small improvement in prompted behaviours. When they drilled down into the data, they found that a child's belief in Santa didn't correlate with this improvement, and neither did the religiosity of the families. Kapitány says this is "not that big a surprise to me, because religious belief itself doesn't tend to be a very powerful predictor of what people do".

Instead, the team found that children who were involved in more of the rituals of Christmas were more likely to perform more prompted prosocial behaviours. Such rituals include putting up decorations, wearing unusual clothes like Christmas jumpers, going to Christmas events and eating festive foods.

"Folks in Western society don't tend to view Christmas as a ritual," says Kapitány, but it matches the definition used by sociologists. He says the findings fit with existing data that a person's social context is a better predictor of their actions than their beliefs. "Many devout theists do good things that are consistent with their beliefs, because the people around them share those beliefs and also do those good things," he says. "It's a reinforcing loop."

However, Risen is more cautious about the purported link between Christmas rituals and children's behaviour, because it didn't show up in all three datasets. "There's an interesting hypothesis here," she says, but it needs "more confirmatory testing", perhaps by randomly assigning children to be given strong reminders of Christmas and comparing them to others.

Despite this, she says that studying children's belief in Santa could yield real insights. Many studies have shown that priming people about religion, for instance by asking them to think about God, can subtly improve their behaviour – but this has only been studied in adults. "Santa is such a natural place to think about it with kids," she says.

Rational belief

In general, ritual can reinforce beliefs in the supernatural, because the sheer amount of effort involved lends the belief credibility. "From a child's point of view, adults and society generally wouldn't engage in all of these otherwise unjustifiable behaviours, putting up trees inside your house, lighting the streets, wearing silly jumpers, eating different foods, singing different kinds of songs, unless what they believed was true," says Kapitány. "So, from a child's point of view, it is rational to believe in Santa, because adults engage in a vast conspiracy to convince them it's true." ▮

Archaeology

Mesopotamians felt happiness in their livers

Colin Barras

THE inhabitants of Mesopotamia must have known grief, fear and love, but didn't necessarily think about them as we do. An analysis of cuneiform texts shows that these ancient people felt happiness in their livers, disgust in their shins and sexual arousal in their ankles.

Emotions map onto the human body in a similar way across large parts of the modern world – some reliably trigger a quickening of the heart or a cold sweat, for example – but it is unclear why. This might reflect underlying biology, but it may also be explained by shared cultural expectations of how we should embody emotions.

To tease apart these two factors, Juha Lahnakoski at the Jülich Research Centre, Germany, and his colleagues have examined how the inhabitants of Mesopotamia almost 3000 years ago mapped emotions onto the human body. The researchers searched for the co-occurrence of words expressing emotions or relating to anatomy in an online library of Mesopotamian cuneiform texts including personal letters and literary epics.

They found that ancient Mesopotamians associated some emotions with body parts in the same way we do. For instance, they linked pride to the heart. This hints at a shared biological basis for embodying certain emotions.

However, the Mesopotamians embodied other emotions differently. For instance, they felt happiness in their liver and anger in their thighs and knees (*iScience*, doi.org/g8tq36). This explains why a Mesopotamian idiom meaning "to be happy" referred to the liver (*kabattu*) being bright (*neperdu*).

The study highlights the "interplay between language, culture and cognition in shaping emotional expression", says Jaume Llop Raduà at the Complutense University of Madrid in Spain. ▮

Artificial intelligence

DeepMind AI predicts weather more accurately than existing forecasts

Matthew Sparkes

GOOGLE DeepMind claims its latest weather forecasting AI can make predictions faster and more accurately than existing physics-based simulations.

GenCast is the latest attempt in DeepMind's research project to use artificial intelligence to improve weather forecasting. The model was trained on 40 years of historical data from the European Centre for Medium-Range Weather Forecasts's (ECMWF) ERA5 archive, which includes regular measurements of temperature, wind speed and pressure at various altitudes around the globe.

Data up to 2018 was used to train the model and then data from 2019 was used to test its predictions against known weather. The company found that it beat ECMWF's industry-standard ENS forecast 97.4 per cent of the time in total, and 99.8 per cent of the time when looking ahead more than 36 hours (*Nature*, doi.org/nvxx).

Weather forecasts rely on simulations requiring huge computing power

Last year, DeepMind worked with ECMWF to create an AI that beat the "gold-standard" high-resolution HRES 10-day forecast more than 90 per cent of the time.

Existing weather forecasts are based on physics simulations run on supercomputers that deterministically model and extrapolate weather patterns as accurately as possible.

97.4%

of the time, the AI model beat an industry-standard forecast

Forecasters usually run dozens of simulations with slightly different inputs in groups called ensembles to better capture a range of possible outcomes. These complex and numerous simulations are extremely computationally intensive and require powerful and energy-hungry machines to operate.

AI could offer a less costly solution. For instance, GenCast creates forecasts with an ensemble of 50 possible futures, each taking just 8 minutes on a custom-made and AI-focused Google Cloud TPU v5 chip.

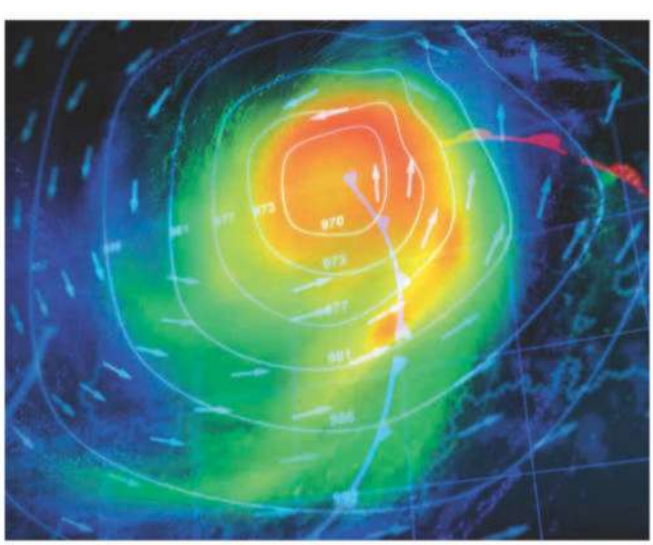
GenCast operates with a resolution of around 28 square kilometres at the equator. Since the data used in this research was collected, ECMWF's ENS has been upgraded to a resolution of just 9 square kilometres.

Ilan Price at DeepMind says the AI may not need to follow suit and could offer a way forward without collecting finer data and running more intensive calculations. "When you have a traditional physics-based model, that is a necessary requirement for getting more accurate predictions, because it's a necessary requirement of more accurately solving the physical equations," says Price. With machine learning, going to higher resolution doesn't necessarily mean more accurate predictions, he says.

David Schultz at the University of Manchester, UK, says AI models present a chance to make weather forecasts more efficient but they are often overhyped, and it is important to remember that they rely on training data from conventional physics-based models.

"Is it [GenCast] going to revolutionise numerical weather prediction? No, because you still have to run the numerical weather prediction models in the first place to train the models," says Schultz.

But for now, GenCast offers a way to run forecasts faster at lower computation cost. Kieran Hunt at the University of Reading, UK, says just as a collection of physics-based forecasts can generate better results than a single forecast, he believes ensembles will boost the accuracy of AI forecasts. ▮



PETROVICH9/STOCKPHOTO/GETTY IMAGES

Field notes Oregon Caves National Monument and Preserve

What stalagmites can tell us about life on a hotter Earth

The way wildfires will continue to change as a result of climate change could be revealed by clues deep underground, finds **James Dinneen**

IN THE event of a wildfire, flee into the cave. This is the official emergency policy of Oregon Caves National Monument and Preserve, a forested area protecting an underground wonder, a labyrinth of passages carved into a rare marble formation high in the Siskiyou mountains. There hasn't been a fire here for a century. But the potential for a conflagration in the dry terrain is palpable. If a fast-moving fire were to burn through, the cave would be the safest place for park rangers to hide.

However, the 1.7-million-year-old subterranean system isn't entirely isolated from any fires on the surface. When one burns above, heat and smoke can alter the chemistry of the water that seeps down through the rock. As it drips into the cave, it can leave behind traces of fire in sheer layers of mineral residue.

Over millennia, this builds up within weird cave structures known as speleothems, which protrude from every surface where water flows, including stalagmites on the cave floor and stalactites on the ceiling.

"It's a snapshot," Katie Wendt, a palaeoclimatologist at Oregon State University, told me when I joined her on a recent expedition into the cave. She is among a growing set of researchers using cave records of wildfires to extend our view of fire activity back hundreds of thousands of years, to a time when temperatures on Earth were even hotter than today.

That, in turn, is offering a fresh view of how we can expect future wildfires to behave as a result of climate change this century.

Speleothems have long been used to understand Earth's climate history. Like tree rings, they preserve in their many layers a chemical record of changes in the environment around a cave, such as in temperature or precipitation. They are especially valuable alongside other records like ice cores or lake sediments because they cover up to millions of years of climate history and can be precisely dated by analysing the slow decay of radioactive elements within them. But "looking at fire in speleothems is still really, really new", says Jessica Oster at Vanderbilt University in Tennessee, one of Wendt's collaborators. "There's a lot that we don't know."

JAY ALDER/OREGON STATE UNIVERSITY

Geologist Sierra Heimel in the Oregon cave system where she conducts research

For decades, researchers have suspected that fires leave traces in speleothems. But only recently have they shown this is a reliable link. Important evidence has come from the Yonderup cave in south-western Australia. When a fire burned above the cave several years ago, researchers who happened to be studying drip water there noticed a spike in certain metals and other compounds generated from burning plants. "The chemistry completely changed after the fire," says Liza McDonough at the Australian Nuclear Science and Technology Organisation.

She and her colleagues later found that such changes consistently left traces in stalagmites in the cave. To demonstrate this, they showed that a record of fire in a stalagmite that had grown over the past 300 years matched fires known within the historical record. This work validated earlier instances of burns indicated in the stalagmite, revealing that fires became less frequent but more intense after Europeans colonised the continent. "It opens up a whole new understanding of the relationship between climate and fires," says McDonough. Speleothems could do for our understanding of ancient fires what ice cores did for the study of ancient atmospheres, she says.

300
Years of fires captured in a stalagmite that match records

10,000
Years of wildfire activity that may be revealed by a Siberian cave

Belly of the Whale

In early October, I joined Wendt and several of her colleagues on a descent into the cave system in Oregon as part of their efforts to identify such "palaeofire" signals in the fire-prone forests of the Pacific Northwest, a first for the region. After donning bodysuits and helmets with bright lights (everyone needed at least two backups), we ducked into the mouth of the cave.

Bulges of flowstone caked in a white mineral substance called moonmilk seemed to drip from the walls like the wax of a giant candle. The stream that carved much of the cave from the marble, named the River Styx in a nod to Greek mythology, burbled alongside the path, and the air smelled like concrete dust.

We passed through spaces that earlier spelunkers – cave explorers – had given names like Petrified Garden, Belly of the Whale and Banana Grove (see graphic, opposite). The thick root of a Douglas fir wound far into the cave questing deep for water.

A school group passed. "Can I steal your job?" one kid shouted, impressed by our suits. "Just study

geology," replied Sierra Heimel, a cave geologist at the preserve, and our guide.

About a kilometre in, we departed the main path at a "squeeze", a narrow channel that forced us to crawl headfirst, then shimmy through a tilted passage barely wide enough to fit our helmets through. After easing around some bat guano, we arrived in a room known as Niagara 2 because of the waterfall formation that dominated one wall. At 120 metres below the surface, this was one of the deepest parts of the cave. "Welcome to my office," said Heimel.

Wendt pointed out a broken stalagmite about the size of a bottle of wine lying on a shelf of rock. Earlier this year, she explained, she and her colleagues found that this stalagmite grew between 132,000 and 123,000 years ago, dating the rock by measuring the ratio of uranium to its decay product thorium within it. This span of time was during a warm stretch between glacial periods called the Last Interglacial; temperatures in many parts of the planet then were slightly higher than they are today.

Fires on Earth have already become larger and more intense in recent years, as our climate has warmed. But there remain large uncertainties about how future fires will behave as temperatures continue to rise, and knowing how wildfires behaved the last time things were this hot could offer deeper insight.

The Oregon cave's record of palaeofires could help with this, but will probably take years. One painstaking step, for instance, involves using a laser to blast away layers from stalagmites a few molecules at a time. And even before that, researchers must understand how exactly speleothems form in their home cave systems, which requires months of carefully measuring drip water and spelunking trips like this. Wendt sometimes must wait beneath a stubborn speleothem for a quarter of an hour to collect a single drip.

But caves are already revealing secrets of ancient wildfire activity elsewhere. For instance, not far south, in California, Oster and her colleagues have used a speleothem record to identify a period of increased swings between wet and dry years around 8000 years ago; burned plant material within the speleothem also enabled them to study changes in vegetation.

The researchers found that this "climate whiplash" led to substantially increased fire activity, which prompted a shift to woodier plants. "We can look at the relationship between climate and fire and vegetation change all in the same record," says Oster. This same whiplash pattern is exactly what the state is expected to see more of with current climate change.

Caves are also revealing the deep history of fire in the great boreal forests of Siberia,

"It opens up a whole new understanding of the relationship between climate and fires"

where megafires in recent years have raised the alarm about more burning and emissions as the Arctic warms.

Jade Margerum at Northumbria University, UK, and her colleagues recently used a stalagmite from Botovskaya cave to reconstruct fires in southern Siberia during the Last Interglacial, and compare this with fire activity over the past 10,000 years. The historical record of fires in the remote region only goes back a few decades, but "if we have caves there, we can fill in these gaps", says Margerum.

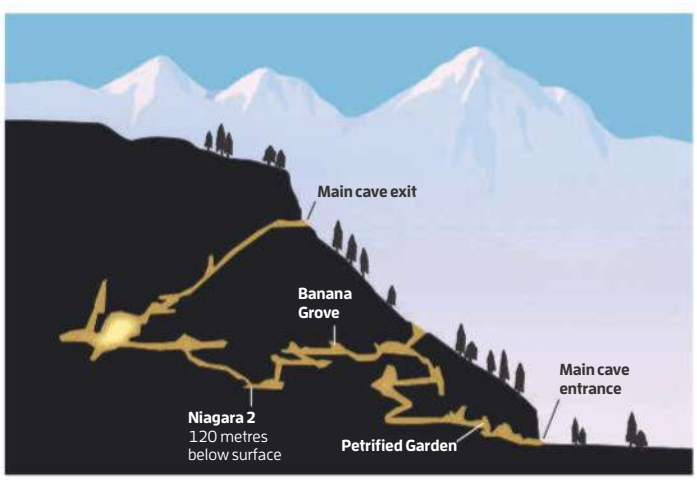
Although temperatures were actually cooling during this period near the end of the Last Interglacial, Margerum's group found a large spike in fire activity.

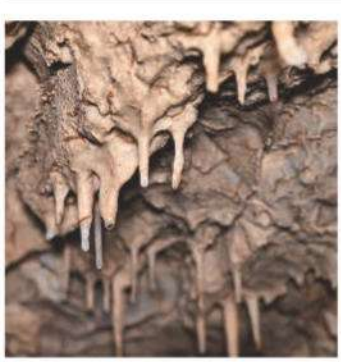
Based on compounds from burned plants recovered from the Siberian stalagmite, they found this jump coincided with a shift to a forest dominated by softwood trees as well as more extreme differences between winter and summer temperatures.

In the context of today's rapidly warming climate, this ancient spike in Siberian fires is concerning, says Margerum, because it suggests large increases in fire can happen even when temperatures are cooling. "Once we've disentangled this, we can then help modellers work out what could happen in the future." ▮

Caving for clues

The Oregon Caves National Monument and Preserve is home to a 1.7-million-year-old cave system where geologists are investigating how wildfires burn on a hotter planet





JAY ALDER/OREGON STATE UNIVERSITY

Chemicals from fires penetrate the ground and leave traces in the drip water that creates cave structures

REUTERS/MATT MILLS MCKNIGHT

Technology

Medical advice chatbot put to the test

People whose medical queries were answered by an AI-powered healthcare app reported high satisfaction levels, but one exchange included "potentially dangerous inaccuracies", says **Alex Wilkins**

A FRENCH health insurance company has tested its medical chatbot with hundreds of people, in the largest real-world trial of a medical AI of its kind.

Technology companies have long promised that their AIs can help ease pressure on doctors by providing accurate medical advice, but critics have been sceptical about their accuracy and potential risks, and they have failed to find wide success. One of the most prominent AI healthcare companies, Babylon Health, went bankrupt last year.

Recent chatbots powered by large language models, such as ChatGPT, appear to offer better accuracy and fluency when providing medical advice than older AI models, and they have shown promise in testing behind closed doors. But there is still scant data for how they might perform with real patients, in part because of the large risks and ethical problems of potentially incorrect or harmful advice.

Now, Antoine Lizée at French health insurance company Alan and his colleagues have tested their AI chatbot, called Mo, in hundreds of real-world conversations.

While using Alan's existing online medical advice service, where people can talk with real doctors over text, people were given the option to talk with Mo instead. "We're the first one to ship the real thing in real conditions and to see how it behaves in front of patients," says Lizée.

Rather than build their own medical chatbot, which some companies like Google have done, Lizée and his team tested several commercial models from companies like OpenAI and Anthropic to power Mo.

They evaluated the models on a test made from hundreds of French medical exams to assess which models might fare better in specific scenarios.

GUIDO MIETH/GETTY IMAGES

More and more people are turning to apps to get answers to medical queries

The researchers also used anonymised conversations that Alan customers had had with doctors and tasked Mo with the same queries, comparing its responses with the doctors'.

To answer patients' questions, Mo draws on the best model for each task based on the strengths and weaknesses identified in these tests. The team gave customers the option to have their queries answered by the AI, and those who accepted were randomly assigned to either Mo or a real doctor. To minimise potential risks, Mo had restrictions on topics it couldn't talk about, including mental health and emergency requests. It also had each of its messages reviewed by a real doctor within 15 minutes of being sent.

The results, which included 926 conversations in total, showed that people who had spoken with the AI reported slightly higher satisfaction and "clarity of information" compared with those who spoke with a doctor.

Out of 1265 messages sent by Mo, 95 per cent were rated positively by doctors, 3.6 per cent were rated as poor and one conversation was flagged for "potentially dangerous inaccuracies" and subsequently hidden from the recipient (arXiv, doi.org/nvxt). The content of the flagged message can't be disclosed due to privacy reasons, says Lizée.

"You can say it's just an individual case, but it could be extremely detrimental to that one person," says Caroline Green at the University of Oxford. "From a safety point of view, this doesn't seem ready at all, and it would be good to know what the dangerous information was. That transparency factor is really important also, to build trust and to know how people are working on improving these systems."

While the metrics of patient satisfaction being tested by Lizée and his team are useful, they are only relevant for this particular chatbot, says Ryan Abbott at the University of Surrey, UK.

"It's difficult to generalise to medical chatbots generally," he says. "You have a very wide range of what [a chatbot] might be dealing with, from someone scheduling an appointment to someone asking a clinical question or for advice on taking medication."

1265
messages were sent by an AI chatbot in 926 conversations

95%
of the messages were rated positively by doctors

1
conversation was flagged as "potentially dangerous"

Under supervision

Lizée and his team say that they plan to continue testing Mo with real people in a supervised manner, aiming to increase the number of responses rated as positive to 99.5 per cent and decrease the number of potentially harmful results to 1 in 10,000.

"We needed to see the right kind of data to go to the next phase, especially in terms of safety," says Lizée. "We're going to continue applying these things. We're not going to send it to all French people tomorrow unsupervised."

But more focused and monitored testing with a group of people in a strict research environment should be carried out before rolling out the AI to the wider public, says Green. "At the moment, I'm not convinced from what I saw in this paper that it's a good idea to roll it out at all. I think it would be unsafe to do. There should be more of a development phase here."

Ancient humans

Toddler bones hint that mammoths were the main food of the first Americans

Michael Le Page

MAMMOTHS made up nearly half the diet of a boy who died in what is now Montana 12,800 years ago, suggesting they were the main food source for people at the time.

"To have it turn out to be 40 per cent, it's just like, wow!" says James Chatters at McMaster University in Canada. When compared with other animals from that time, the diet was more similar to that of the carnivorous scimitar-toothed cat than that of the omnivorous short-faced bear, says Chatters.

Artefacts such as stone tools show that about 15,000 years ago, as the ice retreated after the last glacial maximum, people from Asia crossed a land bridge that existed across the Bering Strait and moved into North America. These people, known as the Clovis culture, developed distinctive stone tools characterised by large, finely made stone points.

While Clovis tools have been discovered at many sites, only one set of human bones has been found alongside them. These bones, now reburied, are of an 18-month-old boy known as Anzick-1. His genome shows that the Clovis people are probably the ancestors of Native Americans.

It has been long been clear that the Clovis people hunted mammoths and other megafauna, but there is debate about how much they relied on them. Some think they were generalist hunter-gatherers who hunted large animals occasionally. Others think they specialised in killing megafauna and that is what their stone tools were designed for.

To investigate, Chatters and his team looked at the ratios of certain oxygen and nitrogen isotopes in the bone collagen of Anzick-1, then compared them with animals from the same time. Different types of plants have different ratios of these isotopes. This, along with the differing digestive systems of the herbivores that eat them, affects the ratios in the herbivores' body tissues. This means each herbivore has a distinct isotopic "fingerprint".

Mammoths were a key part of some human diets 12,800 years ago

MARK P. WITTON/SCIENCE PHOTO LIBRARY

The fingerprints of predators, in turn, reflect those of the herbivores they eat. Anzick-1's fingerprint is between that of mammoths, bison and elk, with a statistical analysis providing the 40 per cent mammoth estimate (*Science Advances*, doi.org/nvx9).

Because of Anzick-1's age, this mostly reflects his mother's diet. The team assumed two-thirds of his diet was milk from his mother, based on weaning ages in modern hunter-gatherers, says Chatters.

"If he had been eating more solid food, the mammoth signal would be even stronger," he says. "What we can say definitively is that this one group was living heavily on mammoth."

"This study provides strong evidence of large animals being a major part of the diet," says Joseph Gingerich at Ohio University. "With this being said, I think the debate may still continue."

Chatters says the findings also support the case that hunting by the Clovis people led many large animals to go extinct. "We're the ultimate invasive species," he says. ▮

Ecology

A good crop of fungi makes plants more attractive to bees

PLANTS with diverse species of fungi living on their roots grow larger flowers, prompting bees to visit them more often.

"[These fungi] might not only have benefits for the plant itself, or for the soil, but also for the pollinators," says Aidee Guzman at Stanford University in California.

Guzman and her colleagues grew squash plants (*Cucurbita pepo*) inoculated with four combinations of different species of mycorrhizal fungi. These fungi live on roots, giving the plant nutrients scavenged from the soil in exchange for carbon.

Once the plants flowered, the researchers moved them from a greenhouse to an outdoor field. Then, for a week, they observed the visits of bees to each plant.

Plants inoculated with fungi received an average of 28 per cent more bee visits than plants that hadn't been treated. The bees also spent 47 per cent more time on their flowers (*New Phytologist*, doi.org/nv2k).

An increase in the treated plants' flower size was the only trait clearly associated with more bee visits.

Not every fungal treatment worked in the same way, though. The plants inoculated with the most diverse group of fungi saw the most bee visits, but other combinations had different effects. Some prompted the plant to divert nutrients away from flowers to their roots, resulting in fewer bee visits. Other treated plants grew more flowers and produced more nutritious pollen, but these changes weren't linked to more bee visits.

CREDIT: ROMAN KYBUS/ALAMY

Bees visit squash flowers more often if the plants have a greater diversity of fungi on their roots

That there can be a trade-off between a plant attracting pollinators and supporting fungi suggests these two different symbiotic relationships could have influenced one another's evolution, says Jon Bennett at the University of Saskatchewan in Canada. ▮

James Dinneen

Welcome to *New Scientist*'s round-up of the biggest stories in science and technology in 2024

Heating up
We just had the hottest year on record for the second year in a row this page >

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A stunning selection of animals from the past 12 months p18

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The private sector has well and truly arrived in orbit p19

A looming threat
Bird flu was a growing concern throughout 2024 p20

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The Anthropocene may be gone, but it isn't forgotten p24

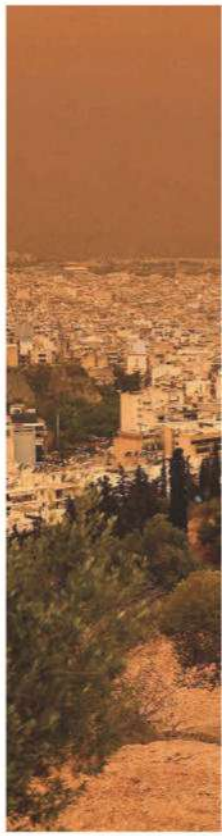
Spare parts
Pig kidney transplants are showing promise despite deaths p25

Environment

Another year of climate breakdown

Heatwaves, storms and wildfires were among the symptoms of our warming world seen in 2024

James Dinneen



REUTERS/LOUISA GOULIAMAKI

IT WON'T be confirmed until January, but it is now almost certain that 2024 will surpass 2023 as the hottest year on record. Even more significantly, the global average temperature is set to show that the planet has warmed by more than 1.5°C since the 19th century – the limit countries agreed to pursue under the Paris Agreement.

But average temperatures are just one way of assessing the rapid changes taking place in the planet's climate in response to our greenhouse gas emissions. From the oceans to the Amazon, 2024 saw a parade of new climate extremes.

Many of these were captured by the 2024 State of the Climate report, a review of 35 "planetary vital signs" released for the past five years by a group of climate researchers. This year's analysis, published in October, found that 25 of these climate indicators reached record levels in 2024, prompting the authors to offer this dire assessment: "We are on the brink of an irreversible climate disaster. This is a global emergency beyond any doubt. Much of the very fabric of life on Earth is imperiled."

Across the oceans, surface temperatures were at record highs for the first half of the year and remain well above average, although they have fallen below last year's levels. The amount of heat stored deeper in the oceans, which have absorbed 90 per cent of the excess heat trapped in the atmosphere since the industrial revolution, continued to climb.

In August, a *New Scientist* cover story explored how all this heat has caused chaos in the oceans, from collapsing fisheries to signs that key ocean currents are changing. The heat has also driven coral bleaching in 77 per cent of the world's reefs, prompting the US National Oceanic and Atmospheric Administration to declare the most widespread mass bleaching event on record. Adding to stress from heat, the oceans have grown more acidic as they continue to absorb carbon dioxide.

The heat in the oceans has also been a factor behind the extremely low levels of sea ice at both poles. For most of 2024, sea ice extent in the Arctic has remained near the record-low levels set in 2012. The persistently low levels of sea ice since 2007 prompted the National Snow and Ice Data Center in the US to call this the "new abnormal". Antarctic sea ice, too, has remained near record lows set in 2023 – and briefly surpassed them – reinforcing concerns that southern hemisphere sea ice is also in the midst of a permanent shift.

"2024 teaches us that we have no time to waste: the consequences of climate change are real, they are here today and they are affecting our lives right now," says Edward Doddridge at the University of Tasmania in Australia, who has raised alarm about low sea ice extent. "The path to net-zero emissions is not an easy one, but the consequences of delay are becoming frighteningly clear."

While missing sea ice is bad news for ecosystems and may have other consequences for polar waters, it doesn't directly affect sea levels. But the ice sheets on land that do contribute to sea level rise are also

melting faster than ever. Both the Greenland and Antarctic ice sheets have lost billions of tonnes of mass in 2024, breaking records, according to the State of the Climate report. In September, a six-year investigation of Antarctica's massive Thwaites glacier projected that its retreat will continue to accelerate, which could eventually trigger the loss of much of the West Antarctic ice sheet and 3.3 metres of sea level rise, although that "doomsday" scenario could take centuries.

Extreme weather has also caused deaths and damage worldwide, from flooding in countries including Ethiopia, Brazil, Spain and Bangladesh to heatwaves affecting the majority of humanity. In Saudi Arabia, a heatwave killed more than 1100 people making the pilgrimage to Mecca. Along with extreme heat across large parts of Asia, India saw its longest heatwave on record, with the mercury passing 50°C (122°F) in some places. The US Southwest and Mexico also scorched under a heat dome. Formal attribution analyses found that each of these events was made more likely or was exacerbated by climate change to some extent.

Fuelled by ocean heat, the Atlantic hurricane season roared to a start with Beryl, which rapidly intensified in early July. After an unexpected lull, a series of destructive storms battered the US Gulf Coast one after the other later in the summer. Heavy precipitation from Hurricane Helene caused devastating flooding far inland, stressing water infrastructure and knocking out a major climate data processing centre in North Carolina.

Saharan dust storms like this one in Athens, Greece (above), are becoming more common. Heavy rain caused severe floods in Porto Alegre, Brazil (below)

MAX PEIXOTO/GETTY IMAGES

Meanwhile, on the Panama Canal, the problem wasn't too much water, but a lack of it, as a severe drought exacerbated by climate change led to disruptive traffic jams on the globally important waterway.

The heat also contributed to another extreme year for fire. According to the State of the Climate report, a record 119,000 square kilometres of forest had burned by October across the globe. A parched South America saw especially significant burning, including some of Chile's deadliest wildfires on record early in the year. Thousands of square kilometres also burned in Brazil's Pantanal wetlands and the Amazon, releasing more carbon into the atmosphere than any other fire season in at least two decades, according to the Copernicus Atmosphere Monitoring Service. Fires in Canada haven't been as extreme as in 2023, but with more than 50,000 km² burned, it still ranked among the worst years. The US has seen a much more active season than in 2023, with more than 30,000 km² burned.

Alongside changes in the climate itself, greenhouse gas emissions are projected to hit record levels, pushing the concentration of the planet-warming gases in the atmosphere to new highs. "The thing that keeps me up at night is not knowing how far down this path we will go," says Doddridge. "Our science tells us that the risks become much, much worse as the world warms. I'd rather not find out just how bad things can get."

Even if emissions start to fall thanks to the continuing acceleration of clean energy development, further warming is already baked in. Expect more extremes to follow in 2025.

James Dinneen is an environment reporter at *New Scientist*

Zoology

A festival of stunning creatures

The past 12 months have seen animals of all shapes, sizes and colours strut their stuff – here are just a few of the best pictures from the year

JAMES TWEED, JAKE BARKER/AUSTRALIAN WILDLIFE CONSERVANCY

MATT BRADY/THE UNIVERSITY OF TEXAS AT EL PASO

APOPO

ARMAS

ROV SUBASTIAN/SCHMIDT OCEAN INSTITUTE

Top row: *Excastra albopilosa*, thought to be the world's fluffiest beetle, and a rare, blue magnificent tree frog *(Litoria splendida)* were both found in Australia

Middle: The yellow-crested helmetshrike *(Prionops alberti)*, found in the Democratic Republic of the Congo, was photographed for the first time ever; African giant pouched rats (*Cricetomys ansorgei*) were trained to sniff out trafficked items such as rhino horn

Bottom: Rakus the orangutan was the first non-human seen treating wounds with medicinal plants; *Chaunacops coloratus* was one of more than 100 newly identified species spotted off the coast of Chile

Space flight

Space was for sale as private missions boomed

Matthew Sparkes

PRIVATE companies reached several milestones in space this year, including the first private lunar lander touchdown and the first civilian spacewalk, and Elon Musk's SpaceX played a key role in many of these missions.

The first big event for the sector this year came on 22 February, when Texas-based Intuitive Machines landed its Odysseus spacecraft on the moon, making it the first private company to achieve a feat previously only accomplished by national space agencies. Despite the lander tilting unexpectedly, the mission was a success and another is planned to blast off early in 2025.

Odysseus was launched on a SpaceX Falcon 9 rocket, making it just one of the many successes for the company this year. The biggest was in September with the Polaris Dawn mission, which featured the first ever civilian spacewalk. Every spacewalk completed before this was performed by government-trained astronauts.

Billionaire Jared Isaacman, who co-funded the mission and served as commander, was the first to partially exit the spacecraft, followed by SpaceX engineer Sarah Gillis. The pair made their "stand-up" spacewalks one at a time as the craft orbited Earth at more than 25,000 kilometres per hour and an altitude of around 740 kilometres. The mission also broke the record, set by Gemini 11 in 1966, for highest orbit (excluding the Apollo missions to the moon), reaching over 1400 km at one point.

Not content with these missions, SpaceX made its third, fourth, fifth and sixth Starship test flights, including the first "catch" of its Super Heavy booster, as the company continues to develop the largest rocket ever built. And

SERGIO FLORES/AFP VIA GETTY IMAGES

it was business as usual, with more than 100 Falcon rocket launches and the deployment of hundreds more Starlink satellites.

In another sign that the private space industry is on the ascendant, the incoming US president, Donald Trump, announced on 4 December that Isaacman would be his nominee for administrator of NASA. Posting on X, Isaacman said: "There will inevitably be a thriving space economy—one that will create opportunities for countless people to live and work in space."

Theodore Tzanetos at NASA's Jet Propulsion Laboratory in California says the commercialisation of space ramped up in 2024 and we should expect to see the trend continue.

"I think it's just the natural way of things," he says. "Costs will go down, risks will go down, reliability will go up. That's just the way of the market. There's been so much investment pushed into space in the last few decades. The commercialisation of space, I think, is going to be a great thing for all humanity."

Davide Amato at Imperial College London says that with SpaceX and Jeff Bezos's Blue Origin we have seen a Silicon Valley-isation of space. They have a build-fast, test-fast approach to rocket design that is unprecedented in the relatively conservative world of state space agencies.

Amato says that while they are pushing innovation faster than ever before, it is ultimately often still governments footing the bill. For instance, Intuitive Machines and others are contracted by NASA to put payloads on the moon. SpaceX generates revenue by carrying military satellites into orbit and ferrying US astronauts to and from the International Space Station. And both Blue Origin and SpaceX are designing landing systems for NASA to carry Artemis astronauts to the lunar surface. ▮

Matthew Sparkes is a technology reporter at *New Scientist*

"Costs will go down, risks will go down, reliability will go up. That's the way of the market"

SPACEX

Jared Isaacman partially exited a SpaceX Crew Dragon craft in September (left). SpaceX's Super Heavy booster was caught in October (above left)

Health

Bird flu suddenly got serious

More than 50 people in the US tested positive for bird flu this year, increasing concerns about its pandemic potential, reports **Grace Wade**

A HIGHLY infectious type of bird flu began spreading in dairy cows across the US earlier this year, providing the pathogen with one of its best opportunities to date to evolve and more easily infect people.

Infectious disease experts have been concerned about the virus, called H5N1, for decades. Of the more than 900 people worldwide who are known to have caught it since 2003, around half died as a result.

For now, H5N1 is poorly adapted to infecting humans and, as far as we know, can't pass between people. But each time a non-human animal transmits the virus to a person or another mammal, it has an opportunity to acquire mutations that could change that.

This is why public health experts were particularly alarmed when a dairy cow in Texas tested positive for H5N1 in March. It not only gave the virus an opportunity to better adapt to mammals, but also put it in close proximity to dairy workers.

Despite these risks, US officials have largely left H5N1 to spread without restrictions in cattle. As a result, more than 690 herds across 15 states had tested positive for the virus by early December.

"What is important to recognise about [H5N1] is that it has already been unprecedented," says Meghan Davis at Johns Hopkins University in Maryland, referring to a subtype of the virus that emerged several years ago, killing tens of millions of birds and thousands of mammals around the world, including foxes, bears and seals. "It has done things that highly pathogenic avian influenza viruses typically don't do. So to have it enter the dairy cow population was really remarkable."

Cows aren't natural hosts for avian flu viruses, which is partly why public health officials were caught off guard by the outbreak, says Seema Lakdawala at Emory University in Georgia. Unlike the chicken or pig industry, the dairy industry in the US doesn't have a robust, centralised system for monitoring and containing flu viruses.

Developing such a system has been complicated by the fact that state governments have jurisdiction over how to respond to disease outbreaks in farm animals, leaving each state to implement its own surveillance method. For instance, Texas has largely taken a hands-off approach, recommending that farmers only test cows that appear sick. Colorado, on the other hand, tests milk tanks on individual farms, as sick cattle shed high amounts of the virus in raw milk.

"What we don't know, which we should know, is how many herds are actually infected in the US – and even when we talk about a positive herd, we don't know how many cows on that herd are infected," says Lakdawala.

It is also unclear exactly how the virus is spreading among cattle, she says. While most evidence points towards milking equipment, which isn't always sterilised between uses, it could also be transmitted via respiratory droplets, she says.

"I had thought after the covid-19 pandemic that, in the face of [another virus] emerging, we would be stronger in our response to prevent another pandemic," says Lakdawala.

Getting to the bottom of how H5N1 is spreading among cows is crucial to prevent it infecting more people. More than 50 people in the US have tested positive for H5N1 this year. Canada also recorded its first case this year in a teenager in British Columbia who, as of late November, was in a critical condition.

The Canadian teenager, along with one case in Missouri and another in California, had no known contact with animals or raw milk, so it isn't clear how they contracted the virus. Everyone who has been infected so far has fully recovered and most have only experienced mild symptoms, such as eye redness. This death rate is very different from what has generally been recorded since 2003, which may be a reflection of different healthcare services around the world or how the virus enters the body. For instance, infections that arise via the eyes are thought to be more severe than those that start in the airways.

While no human fatalities have occurred so far in this outbreak, there are some indications that the virus is adapting to more readily infect mammals, says Lakdawala.

SUZANNE KREITER/THE BOSTON GLOBE VIA GETTY IMAGES

Cattle herds, and some dairy workers, across the US caught bird flu this year

"I thought post covid-19 we would be stronger in our response to prevent a pandemic"

For example, a genetic analysis of a sample collected from the person in Missouri led to the identification of a mutation that seems to diminish the ability of antibodies to recognise and neutralise the virus.

It is too early to know whether this and other mutations will make H5N1 more dangerous to people, but as long as the virus circulates freely among dairy cows, it may just be a matter of time before that is the case.

"At this point in the outbreak, we should have a better handle on some very basic fundamental questions," says Lakdawala.

Grace Wade is a health reporter at *New Scientist*

Technology

Neuralink's brain implants were on our minds

Matthew Sparkes

ELON Musk's brain-computer interface (BCI) company Neuralink grabbed headlines this year with the announcement of its first human trial in January, followed by its second in August. The firm aims to mass-produce a tiny, implantable chip that will initially allow people with paralysis to control computers with their mind, before a wider rollout for anyone who might want it.

The company's first subject, Noland Arbaugh, said that the device was "like using the Force [from *Star Wars*] on the cursor". He had a coin-sized chip implanted on the surface of his brain, with 64 extremely fine electrode threads weaved directly into the brain by a surgical robot.

A month after the procedure, however, some 85 per cent of those electrode threads had shifted, dramatically reducing Arbaugh's ability to control a computer. Software changes later reversed some of that decline, and the procedure for the second subject's implant was changed to reduce the chance of similar thread retraction, the company said in an update in August.

"A month after the procedure, most of the tiny threads in the brain had shifted"

JOHN FRANCIS PETERS

Noland Arbaugh was the first person to receive a Neuralink brain implant

Since then, Neuralink has gone silent, with only occasional blog posts from the company and snippets of information from Musk. The billionaire founder announced earlier this year that Neuralink is working on another device called Blindsight, which he said in a post on X will "enable even those who have lost both eyes and their optic nerve to see". The firm didn't respond to a request for comment.

Despite the media attention it receives, Neuralink is far from the only group developing BCIs. Tom Carlson at University College London, who works with non-invasive BCIs that use electroencephalography and require no surgery, says there will be applications for a variety of different devices depending on the user's health problems, intended use and appetite for risk.

"It's not VHS versus Betamax," he says, though he concedes that invasive devices such as Neuralink's can get "closer to the signal" and are likely to offer more accurate control.

Carlson says that Musk's backing has enabled Neuralink to invest heavily and recruit skilled researchers. This has allowed it to catch up with other groups that began work years before, and has probably brought the company near to the state of the art. But the lack of detailed information is troubling.

"I think the concern that the scientific community have around the approach is that it's a bit of a black box from the outside," says Carlson. "There's been very little in terms of scientific publishing and peer review. I think there's a lot of value in open science. If you report negative results, it saves other people from making the same mistakes. And I think that's possibly something that the community feel is a bit missing here."

Artificial intelligence

The shine began to wear off AI as advances slowed down

Alex Wilkins

DID artificial intelligence begin to plateau in 2024, following a boom year in 2023? It depends on who you ask. Some say AI models that were released this year and can apparently reason more effectively than their predecessors show that the lofty goal of artificial general intelligence (AGI) is still on track, but not everyone is convinced.

Certainly, tech firms have continued to talk up the hype. When it launched GPT-4 in 2023, OpenAI boasted that the model had "human-level" performance on professional tests in fields like law and medicine, while researchers at Microsoft (a significant investor in OpenAI) claimed it showed "sparks" of AGI. The next iteration, GPT-5, would perform like a PhD student, according to OpenAI executives.

However, as this issue went to press, OpenAI had yet to release GPT-5, while known issues with this type of large language model (LLM) persist, says Melanie Mitchell at the Santa Fe Institute in New Mexico.

"There's still obviously quite a lot of problems with these models," says Mitchell. "They're not very reliable, and they do seem to be brittle in certain ways, meaning that they don't perform well on certain things that are sufficiently different from what they've seen in their training data."

While newer models have achieved higher scores on certain measures of chatbot capabilities, these jumps in performance have become increasingly small. In April, Gary Marcus at New York University highlighted this as one of the reasons he believed that LLMs were entering a new "period of diminishing returns".

However, the release of OpenAI's o1 model in September is a "large step" towards more capable models, says Noam Brown at OpenAI. "There were legitimate reasons to be concerned about AI plateauing," he says, such as the increasing cost required to train larger and larger models. But o1 could change this paradigm, he says, because of the way it calculates its answers.

Unlike GPT-4, which is fed data and trained once, often taking vast amounts of computing power for months at a time, o1 instead uses more computing power to answer individual questions, which Brown compares to the way humans take time to carefully think through their answers to problems.

"Previous models would do all their computation upfront, and when it came time to actually query them, they would respond basically instantly," he says. "With o1, you see this difference where it's spending a lot more time thinking about how to respond to the question before actually responding."

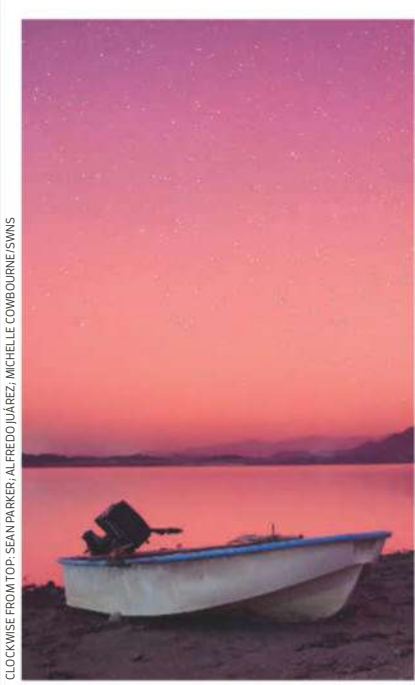
Google DeepMind has also been experimenting with AI that can tackle tasks requiring reasoning, such as its AlphaProof system, which achieved a silver medal score at this year's International Mathematical Olympiad, the first time any AI has attained a medal-level performance.

These advances are promising, says Mitchell, but as companies don't share full information on how their models work, it is difficult to test the claim that the models are reasoning in the same ways humans do.

"There's been a lot of debate about what we should consider to be reasoning," says Mitchell. "Being able to take what you have learned and generalise it to new situations in a robust way is still something that AI has not really conquered." ▮

Alex Wilkins is a reporter at *New Scientist*

"There's still obviously quite a lot of problems with these artificial intelligence models"



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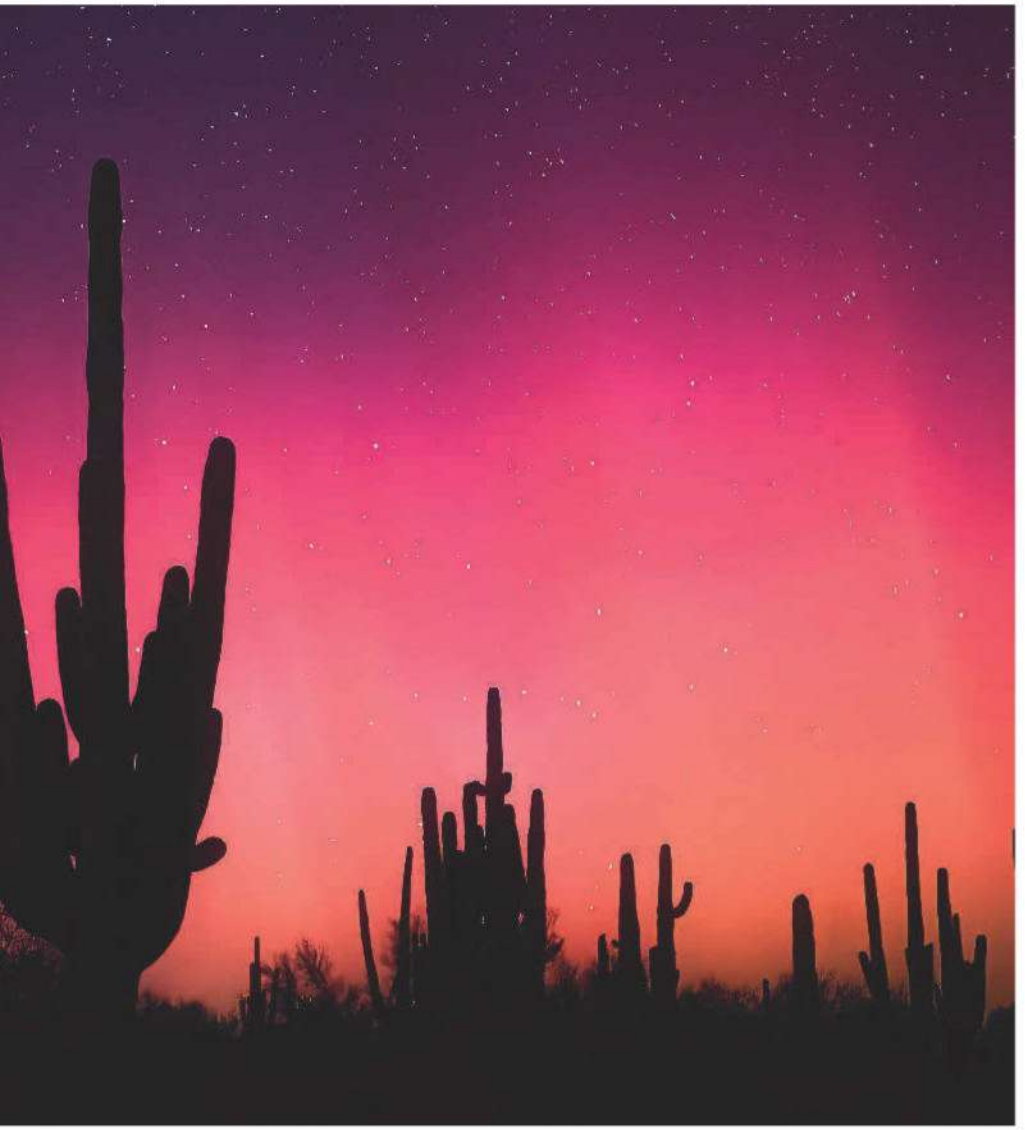

In May, auroras turned the night sky amazing colours in Tucson, Arizona, (above) and as far south as Sinaloa, Mexico (left). Another spate of northern lights in October blazed over Glastonbury Tor in the UK (below)

Space

Dazzling auroras lit up the skies – and we can expect more

SEEING the northern lights, or aurora borealis, typically requires travelling to frosty climes as far north as Norway or Iceland, but this year they have been visible in London, southern Europe and even Mexico. There were two big light shows, in May and October. While the October event was a result of a straightforward solar storm, scientists are puzzled about the storm that caused the May aurora.

"We're still quite surprised how far south the aurora was seen," says Mathew Owens at the University of Reading, UK. "In terms of the geomagnetic impact, the storm was big, but not a 1-in-100-year storm."

One interesting feature of May's solar storm was that it wasn't a single event, but several, says Owens. Unlike October's light display, which was caused by a fairly typical large solar flare pointed directly at Earth, the May one was caused by smaller storms that interacted with and amplified each other on their way to Earth, he says. "It's quite a different solar driver. It's the same phenomenon, a big solar eruption, or what we call a coronal mass ejection, but from a series of events, rather than one big event."

May's aurora also shows how hard it is to predict how space weather will affect Earth, says Owens. The link between the size of the solar flare, the resulting geomagnetic storm and where we see the northern lights is complicated and chaotic, he says.

Seeing two large solar storms in one year isn't unusual, but there has been an alignment of factors that has meant we have seen more auroras, one of which is the time of day – after sunset – that the storm arrives, says Jim Wild at Lancaster University, UK.

Further auroras may be in store during the rest of the current high period of solar activity, called the solar maximum, which could continue for the next year. AW

BONNIE JO MOUNT/THE WASHINGTON POST VIA GETTY IMAGES

Researchers collecting a sediment core sample from Crawford Lake, Canada (left). The sediment layers (below) record changes in the environment over time

Earth science

What next for the Anthropocene?

An official body rejected a proposal to declare a new geological epoch, but its proponents will carry on highlighting humanity's impact on the planet, says **Chen Ly**

A LONG-STANDING effort to formally place the Anthropocene on the geologic timescale came to a surprising end this year. In March, a panel of academics rejected the proposal to define a new epoch by 12 to 4 votes. Yet for the team behind the proposal, work on defining the term – which highlights rapid, human-induced changes to Earth – continues.

As it stands, the Holocene, which began about 11,700 years ago, remains the current epoch. It broadly covers a period of planetary stability during which human civilisation flourished. However, some scientists believe that the increasing impact on Earth is enough to herald a new epoch: the Anthropocene. Over the past decade, a group of scientists called the Anthropocene Working Group (AWG) has been tasked with defining this potential epoch.

In 2023, the AWG submitted a proposal to its parent body, the Subcommission on Quaternary Stratigraphy (SQS), to establish the Anthropocene as an epoch beginning in the early 1950s. Crawford Lake in Canada was proposed as the marker site, with radioactive isotopes from mid-20th-century nuclear fallout preserved in its sediment serving as distinct geological evidence to mark the new unit of time.

The proposal faced an abrupt challenge in March when news of the SQS's decision leaked to *The New York Times*, revealing that 12 SQS members had voted against it, four voted in favour and two abstained.

"We were obviously highly disappointed," says Colin Waters at the University of Leicester, UK, an AWG member. "We were never formally sent a rejection statement. We only found out second-hand. Normally, you're given an opportunity to make amendments to your submission."

Arguments against defining the Anthropocene as an epoch include the idea that a period spanning just over 70 years doesn't fit with units on the geologic timescale, which typically span thousands of years. Furthermore, large-scale human activities, such as the industrial revolution and agriculture, extend centuries before the proposed start of the Anthropocene.

PETER POWER/AFP VIA GETTY IMAGES

Chen Ly is a freelance science journalist

"The rejection doesn't change the reality of the rapid, unprecedented transformations occurring on Earth"

Some scientists have proposed that the Anthropocene be considered a geological event: something that contributes to the transformation of Earth's systems, but doesn't constitute a new unit of geological time. "That includes all human impacts going back tens of thousands of years," says Jan Zalasiewicz, also at the University of Leicester, who is a member of both the AWG and SQS. "It's a valid concept but a wholly different concept."

Initially, the AWG signalled that it planned to appeal the decision, but it ultimately chose not to take formal action. Shortly afterwards, the AWG was formally disbanded.

Now reborn as an informal group of more than 50 scientists, including Waters and Zalasiewicz, the team's commitment to the Anthropocene continues. The group faces two possible paths forward: resubmit a revised proposal for the Anthropocene as an epoch or focus on designating Crawford Lake as a marker for a geologic age, a smaller unit of time within the Holocene. However, it is unclear how long either approach would take.

"It's a shame: the Anthropocene has been used in many ways by many different people," says Zalasiewicz. "This dilutes its usefulness and makes it more confusing."

Despite the setback, the concept remains powerful, symbolising the profound human impact on Earth's systems. "There will likely be those who use this rejection to claim that human-induced change is a gradual, natural shift," says Waters. "That doesn't invalidate the term Anthropocene, nor does it change the reality of the rapid, unprecedented transformations occurring on Earth." ▮

Health

Pig kidney transplants offered new hope

Grace Wade

ON 16 March, Richard Slayman became the first living person to receive a genetically modified pig kidney. Less than one month later, Lisa Pisano became the second. Both died shortly afterwards, but their surgeries were still a significant achievement in xenotransplantation, the transfer of animal organs to people.

Only two other people have received a genetically modified animal organ while alive: David Bennett in 2022 and Lawrence Faucette in 2023. Both were recipients of transplanted pig hearts and experienced complications, which may have contributed to their deaths. Surgeons have also previously transplanted pig kidneys into non-human primates and people who were brain dead and on life support.

These procedures paved the way for Leonardo Riella at Massachusetts General Hospital and his colleagues to transplant a pig kidney into Slayman, aged 62, who was experiencing complications from dialysis and had kidney failure, heart disease and type 2 diabetes.

"It is devastating to see someone pass away waiting for an organ"

MICHELLE ROSE/MASSACHUSETTS GENERAL HOSPITAL

Surgeons transplanting a pig kidney into Richard Slayman in March

His doctors estimated that there was less than a 5 per cent chance he would get a donor human kidney in the next five years, by which point there was a greater than 75 per cent chance he would have died or become too sick for a transplant. "Unfortunately, there was no other treatment available," says Riella.

The organ he received had undergone 69 genetic modifications to make it more compatible with humans and reduce the likelihood of it being rejected by his immune system.

The procedure lasted 4 hours and Slayman was discharged from the hospital within days, but died 52 days later from cardiac arrest. The autopsy showed no connection between his death and the pig kidney, which appeared to be healthy, says Riella.

Jeffrey Stern at NYU Langone Health in New York and his team performed a similar operation on Pisano, aged 54, on 12 April. Pisano, who had both heart and kidney failure, had been fitted with a mechanical heart pump about a week earlier.

The surgeons had to remove the pig kidney after 47 days because it was being damaged by Pisano's heart medications. She died in July.

It is highly unfortunate that both recipients died, but it is still reassuring that neither of the transplanted pig kidneys appears to have directly contributed to their deaths, says Riella. He is in discussions with the US Food and Drug Administration about doing a small trial in people and hopes it could begin within a year.

More than 100,000 people are awaiting an organ transplant in the US, 17 of whom die each day. "It is the most devastating thing to see someone pass away while they're waiting for an organ," says Stern. "My hope is that xenotransplantation will make it so that one day, no one has to go without an organ." ▮

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Columnists

Sleep it off

New Scientist's columnists take a look back at 2024 – plus a wintry instalment of Future Chronicles, an imagined history of inventions

Future Chronicles

Rowan Hooper on how, by the 2050s, hibernation technology allowed humans to skip winters

ADRIÀ VOLTÀ

ALL over the northern hemisphere, millions of animals are tucked up somewhere safe, hibernating through the cold, ready to come up smiling in spring. Bats, marmots, hedgehogs, bears. And not just in the wintry north: animals in the tropics do it too, such as some fruit bats and one primate, the dwarf lemur. It had long been a dream to copy the process in people – and by the 2050s, it had become a reality.

Animals hibernate at different "depths", with varied reductions in metabolism and body temperature. Arctic squirrels are the champions, dropping their metabolic rate by 98 per cent and their body temperature to a freezing -3°C (27°F). It wasn't possible to replicate such extremes in humans without risking cardiac damage, but people could tolerate a gentler, bear-like hibernation. Bears, and humans entering the physiological state of reduced activity known as torpor, enjoy fairly shallow hibernations, cutting their metabolic rate by 80 per cent and decreasing body temperature to 31°C (89°F).

Earlier in the 21st century, cryopreservation – infusing people with ice-cold saline to reduce body temperature – began to be used on those with life-threatening wounds or diseases. But it was a gruelling process if you just wanted to skip winter, and it wasn't great for the skin either. When the genetics of hibernation were uncovered in a range of mammals, then activated in humans, this allowed less-intrusive, "natural" hibernation.

The trick is to first activate genes that reduce metabolism, then get the body temperature down. If you do it the other way round, you have a fight on your hands, as the metabolism tends to try to accelerate in order to combat the temperature loss. Scientists had found ways back in 2019 to trick the brains of pigs and rats into entering torpor, and the method was modified to work in humans.

Deep hibernators such as Arctic squirrels live off their fat for long periods, without drinking or passing waste during their hibernation. Shallow hibernators such as bears bring food with them and wake up from time to time to snack. Since humans undergo bear-like hibernation, this was the protocol used, but with small amounts of food inserted directly into the stomach by a tube. The method meant that people didn't need to gain a lot of weight before hibernation, and it stopped deterioration of essential gut symbionts – which in hibernators recycle nitrogen that is normally lost as waste, for use as a nutrient.

Many people used hibernation as animals do – to skip the winter. It was done not so much to avoid the gloomy symptoms of seasonal affective disorder as to enjoy a boost in lifespan. Biologists knew hibernating animals live longer than non-hibernators of the same size, because their bodies age more slowly during hibernation. In a state of deep torpor, recycle and repair pathways in the body are switched on and cells undergo what is effectively a deep clean. All the bits of damage that contribute to ageing are mopped up or fixed. Human life expectancy, boosted by cycles of hibernation, reached 130 to 150 years.

This breakthrough initially caused great upheaval, worsening inequalities in society as rich people paid to extend their lifespans. Human hibernation centres had to be guarded and sited in secret locations, to prevent attacks by the non-hibernating masses. Eventually, governments intervened to regulate access to the technology. Most countries offered hibernation as a state-provided health resource, giving everyone access to the benefits.

Society became highly intergenerational, something that previously was only pronounced at Christmas and other times when extended families got together. ▮

No planet B

Graham Lawton looks hard to find some green shoots of hope amid general despair about the climate

WRITING about the environment can be depressing and repetitive, and I am relieved that I have been able to take a break from it this year to focus my attention on biomedicine and health stories. But I have still kept an eye on progress, or lack of it, and can say with confidence that it is still depressing and repetitive. This has been another terrible year for the planet.

The litany of woes is wearily familiar: record temperatures, extreme weather, the continued collapse of nature and tides of waste and pollution. So is our collective global response. *Don't Look Up*, indeed!

In November, the latest round of biodiversity negotiations, held in Cali, Colombia, delivered what we described as a "big flop for protecting nature". Meanwhile, the science just continues to deliver bad news. A report from the Zoological Society of London and the World Wildlife Fund, for example, found that the collapse of biodiversity is accelerating. Its 2022 report found populations of wild vertebrates had declined by 70 per cent since 1970. This year, the figure reached 74 per cent.

The climate is faring no better. In October, a group of leading scientists issued a bleak assessment of 35 key "planetary vital signs", finding that 25 of them are in their worst-ever state and that Earth is on the brink of an irreversible climate disaster.

This calendar year also looks certain to be the first to be 1.5°C warmer than the preindustrial era. According to an analysis by the climate news outlet Carbon Brief, 3 out of 5 of the leading research groups that track global surface temperature are predicting with some certainty that we will overshoot that figure. Only the US National Oceanic and Atmospheric Administration (NOAA) thinks we won't, mainly due to differences in the methods it utilises to estimate global temperatures prior to 1900. But even NOAA predicts that 2024 will be the warmest year on record, beating the current holder, 2023, by some margin.

Speaking of NOAA, it is reportedly in for a bashing from the upcoming administration of US president-elect Donald Trump for producing data he doesn't like. His disdain for environmental protections appears to know no bounds and, like many environmentalists, I shuddered at the prospect of him winning and despaired when he did. But on this front, maybe I am being too pessimistic. In the days after the election, I received a flurry of media statements and invitations to press conferences dissecting the likely impacts of his second presidency.

The take-home message was that, while not good news, Trump 2.0 won't halt the unstoppable progress towards a clean energy economy and probably won't lead to a domino-effect collapse of climate change negotiations. Small mercies.

But the fact remains that the climate and biodiversity crises barely got a look-in during the US election campaign. Maybe if they had, the Democrats would have done better: the result of the UK election showed that climate action is electorally popular.

Next year, I will be back on the environment beat and hope to bring better news. There were some green shoots of hope this year – the vital signs report found record levels of consumption of solar and wind energy and divestment from fossil fuels, and a decline in the rate of deforestation in Brazil. Yet, overall, our collective inability to solve these interlinked crises continues unabated. ▮

Lost in space-time

Chanda Prescod-Weinstein recalls a year that saw an existential crisis deepen, and how physics can help

THIS year, both the UK and US had major elections where the governing party lost in a big way. At moments like this, we usually focus on what these kinds of shifts will mean, if anything, for everyday life. Less at the forefront of people's minds is the impact on scientific research. There is a tendency to think of this endeavour as separate.

But the truth is, it isn't. There is a very obvious reason why we can't think of the politics of those in power as separate from what happens in the world of science. Our government agencies are among those tasked with researching and preparing for climate change. It is thanks in part to NASA data that we know 2024 will be the hottest year on record for our planet. Whoever is in the White House is actually NASA's top boss. The National Oceanic and Atmospheric Administration is another US government agency that plays a key role in understanding how climate change is happening. Without such research, our ability to understand how quickly climate change is setting in and what that means for the lives of everyday people could be harmed.

This isn't hypothetical. At the time of writing, my best friend has been without potable water in Asheville, North Carolina, for almost a month and a half. This city was meant to be a climate haven, due to its moderate weather. But it was hit by Hurricane Helene in September, in a scenario that experts say is only likely to happen as part of an escalation of climate change. Not only was Asheville's water system severely damaged, but parts of the mountain forest that surrounds it were also wiped out.

ADRIÀ VOLTÀ

Where there were green, carbon dioxide-consuming trees, there is now a massive arboreal graveyard.

Climate change research not only helps us all demand that our political leaders do something about the growing crisis, but it also helps us predict how that crisis will unfold. If we know more about how hurricanes work, we will be better able to prepare for them. Of course, ultimately the goal has to be to minimise how much change occurs at all.

In some ways, it might already be too late. But every day is a new day to do better. Climate change is an existential crisis for humanity. Will the coming generations have an atmosphere and weather conditions that are friendly to life as we understand it? We are making that decision right now.

And this is the part where other science comes in. It isn't all about the atmosphere. For example, research about bees matters because they help pollinate up to one-third of the food we eat. Our ecosystems are incredible networks with a lot of mutual dependency. Every little microbe is significant.

However, as you may know, I am not a biologist but do research in theoretical physics that has no obvious practical applications.

It still matters though. The work I do helps us remember the bigger picture and to ask the questions that shape how we live our lives. At its core, such work is concerned with fundamental questions of human existence in the context of the wider cosmos. This is, of course, connected with why we must proactively respond to climate change, which I have already called an existential crisis.

Scientific research across many disciplines plays a role in helping humanity think through how to make meaning of why we are here and why we should continue. In the case of particle physics, cosmology and astrophysics, we help everyone remember that there is still so much opportunity to connect with our cosmos – if we will just give ourselves a fighting chance to be part of its future. ▮

This changes everything

High-tech archaeology is showing us we aren't the first to live through testing times, says Annalee Newitz

MORE than 2000 metres above sea level, on a grassy mountain plateau in eastern Uzbekistan, two archaeologists out for a stroll discovered something astonishing. This chilly, wild landscape was once home to two sprawling cities, whose markets bustled with travellers from the Silk Road trade routes that linked China to the West. All that was left of these millennia-old communities were thousands of pottery shards, scattered across the plateau – and the heavily eroded earth mounds and troughs that marked where buildings, walls and roads once stood.

Luckily, researchers Farhod Maksudov at the Uzbekistan Academy of Sciences and Michael Frachetti at Washington University in St Louis, Missouri, were able to uncover the cities' lost infrastructure without lifting a single shovel. They did it with drone-mounted lidar, a remote sensing system that uses lasers to create 3D maps of terrain.

Analysis revealed Tashbulak, a 12-hectare city about 5 kilometres from Tugunbulak, which occupied a whopping square kilometre-plus. In a paper out this year, scholars described the citadels, plazas, industrial workshops devoted to metallurgy, and high-density housing of the twin sites. Their existence challenged many long-held beliefs about the locations of central Asian trade routes over a thousand years ago.

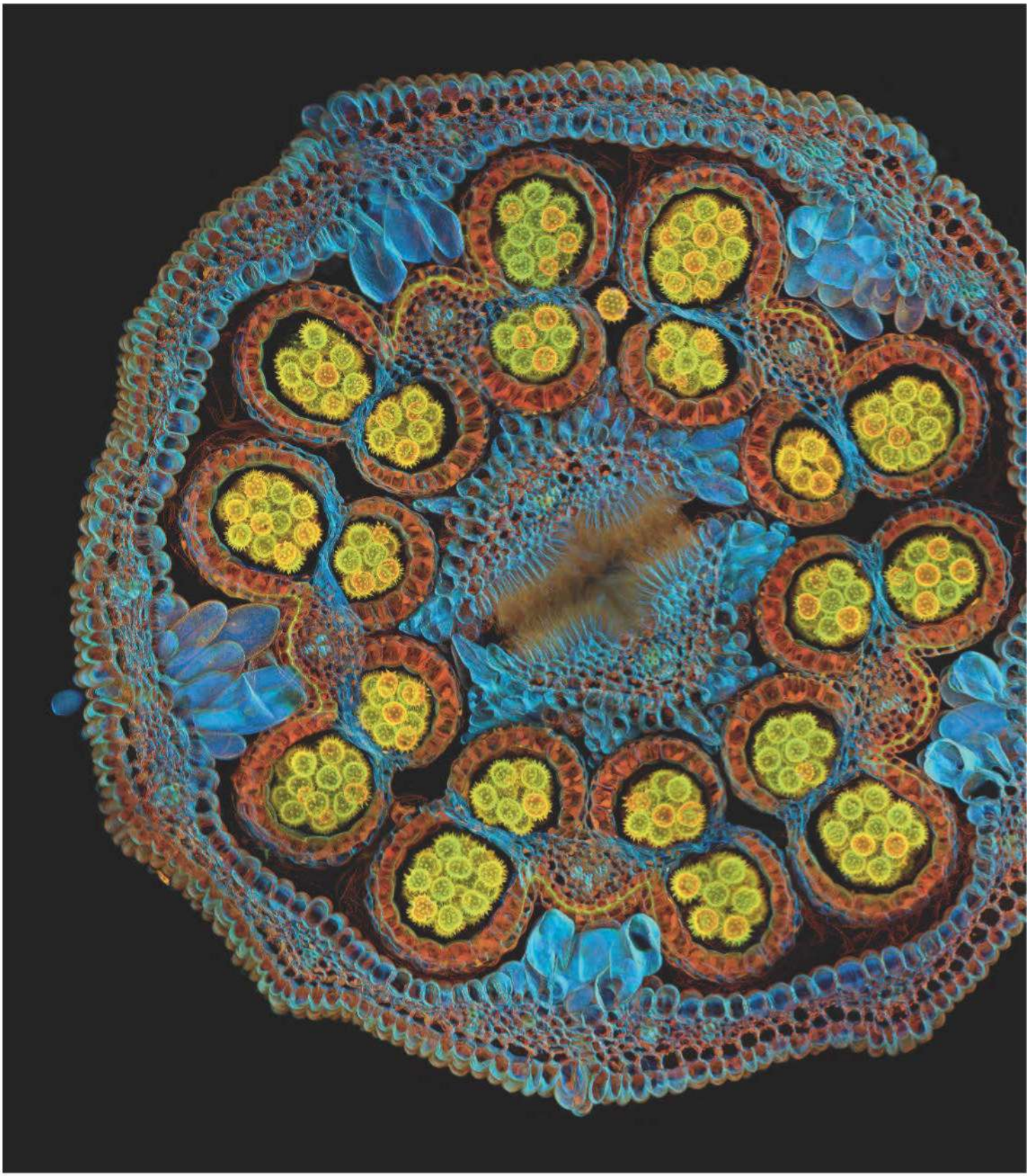
2024 was a banner year for ancient historical discoveries made possible by such methods. Archaeology graduate student Luke Auld-Thomas at Tulane University in Louisiana published a paper about how he found one of the biggest Mayan cities in Latin America. He did it from his computer, using lidar data from a survey done in the Mexican state of Campeche years earlier.

This ancient, deserted metropolis, dubbed Valeriana, lies deep in the heart of a tropical forest. It had elevated causeways, ball courts for sporting events, plazas, terraced farms, a dam and a deep reservoir. Lidar is the perfect tool for discerning features hidden by vegetation, and the city today is entirely obscured by jungle. But back in the 8th century, the inhabitants used their ingenuity to convert such an environment into an urban paradise, with room for nearly 50,000 people.

Valeriana's heyday was around the same time that Silk Road traders were streaming through Tashbulak and Tugunbulak, probably snacking on dumplings. (Yes, there is ample evidence that Silk Road travellers ate such fare.) The connections forged with these ancient cities gave rise to cross-cultural traditions and long-distance commercial relationships whose sophistication might rival those urbanites experience today.

It is also possible that Valeriana and the twin cities of Tashbulak and Tugunbulak were abandoned due to problems that many modern people would recognise with a groan. Auld-Thomas and his colleagues suggest that climate change may have led to droughts that made Valeriana unsustainable at such a large population size. And the fortunes of Silk Road cities rose and fell with the political empires that controlled supply chains across the trade network. When profits dried up, the city slickers of medieval Uzbekistan may have left for greener pastures.

A thousand years on, many of us once more face climate change and political instability. What high-tech archaeology reminds us is that we aren't the first people to live through such times. If our ancestors survived them, so can we. ▮



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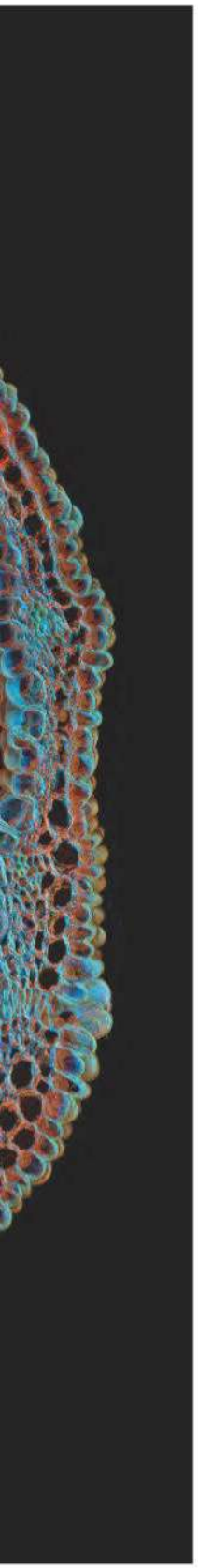

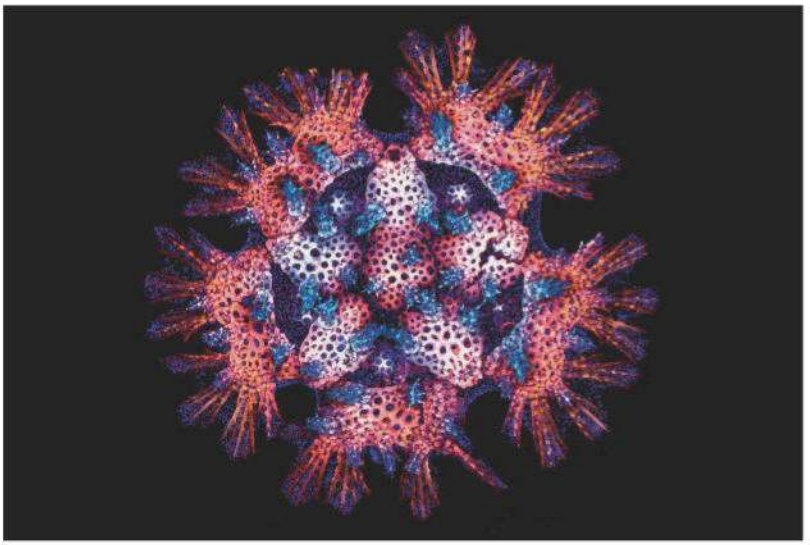

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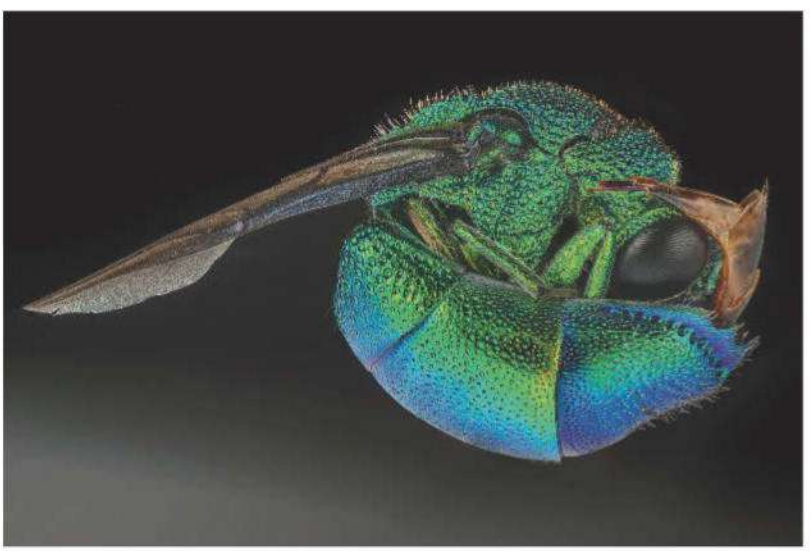

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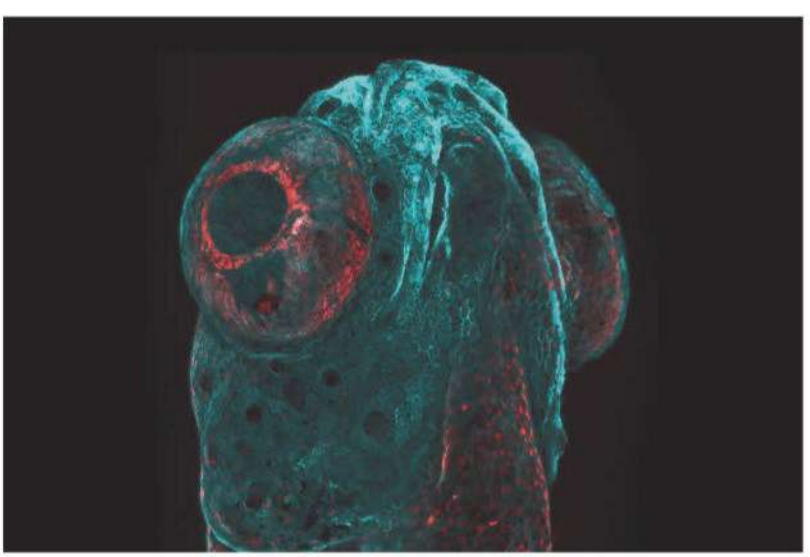


YUE RONG TAN

Little beauties

Evident Image of the Year Award

THESE exquisite images reveal some of the intricate views of animals and plants captured by researchers from 29 countries who entered the Evident Image of the Year competition. The prize recognises the best in scientific microscopic imaging worldwide.

The winning entry (far left) shows a cross-section of a bloom from the "Cosmic Orange" variety of the Mexican aster (*Cosmos sulphureus*), with pollen grains maturing inside its anthers. It was taken by Igor Siwanowicz, a research neurobiologist at the Howard Hughes Medical Institute in Virginia.

Siwanowicz, who collected the flower buds for his shot on a post-lunch walk around the campus pond, said in an announcement about the prize that he chose to enter the image because it "shows that the beauty of a common flower that most of us take for granted can extend beyond what we can see with the naked eye".

"The beauty of natural form and design is present on very different scales, sometimes almost in a fractal manner – as we continue to zoom in, the form may lose familiarity, but also become a new emotional experience," he said.

The smaller images shown here all won honourable mentions in the contest for their views of a variety of animals. In the shot at top, Laurent Formery used vivid stains to highlight the skeleton of a juvenile sea star (*Patiria miniata*) from the Asterinidae family.

Below it is an image of a cuckoo wasp, resplendent in its iridescent colours, captured by Raghuram Annadana, with the bottom image showing a zebrafish head, taken by Yue Rong Tan.

Liz Else

Abracadabra

Award-winning science fiction and fantasy author **Nnedi Okorafor** journeys to the near future in this unsettling short story

JONHOBRIANKO

SINCE my 20s, my breasts have had so much going on in them that they feel like bags of small toys like marbles, toy soldiers, and Hot Wheels. My doctors say it's natural, normal, for me. Just the cards I've been dealt. But for this reason, for decades, I've been squeezed by doctors, smashed four times a year by mammogram machines, poked with biopsy core needles, and cut by scalpels. I've had lymph nodes removed, I have scars, there are several tiny titanium chips in my breasts to mark biopsied lumps. I've had to explain all kinds of shit to curious boyfriends. And it doesn't help that I'm high risk; my mother passed away from breast cancer when I was 25, her sister when I was 30 and my father's sister is a survivor. I am 53 years old and the doctors haven't found any cancer in my breasts. I've simply been tortured by modern medicine's antiquated methods.

I own a successful tea shop. In it, I play neo-soul from the 90s and serve freshly made puff puff, lotus paste buns, croissants, churros and beignets made by my best friend who owns a bakery specializing in pastries from around the world. I love the different types of people I meet every day; tea lovers are as diverse as tea's multicultural origins and subsequent social significance. I don't worry about much. I live an active life of joy. I vibrate at a calm frequency.

Except when it comes to my breasts.

So there I was in that waiting room having an existential crisis. Yet again. Waiting for the radiologist's prognosis for the most recent breast lump that I'd discovered a week ago. I had done my usual monthly self-examination. I know where everything is. The "small toys" in my breasts don't cause me panic...except when a new one shows up. This new lump was big. Did I finally have cancer? Who would run my shop if I had to go through chemo? What if what if what if. Already, my life felt derailed. I wasn't ready.

Rita, the radiologist, came out. "Yeelen? Come into my office," she said. "We can talk there."

My belly fluttered. "Oh, uh, sure," I said.

I followed her down the hallway. I'd known Rita for years and had never noticed her office around the corner. It was warm with rose-colored walls and a large framed print of a woman in a wide brimmed hat drawn with a thick black line. Her left breast was the only color in the image and it was fuchsia, yellow and sky blue.

Rita sat on a plush brown leather chair at her desk. On it were a laptop, photos of her family, and a stack of dusty-looking medical books. I sat on the identical chair across from her. "Ok," she said. "First of all, you're fine. We're almost positive the newest lump is just a fibroadenoma."

"Oh, thank *goodness*," I blurted, sinking into the chair.

She smiled. "The characteristics and imaging strongly suggest it's benign. Most likely, it's hormonal, especially since you're not menopausal yet. *But* because it's a new lump, you're high risk and you're 53, I'm recommending a biopsy. It's the only way to be 100 percent sure."

I groaned, "Noooo." Biopsies meant being stuck with a needle yet again, risk of infection, and, even if relatively short, a recovery. It was invasive surgery and it would be my fourth time having it.

"I'm sorry, Yeelen," she sighed. She pursed her lips and said. "There is an alternative, if you're interested."

"No, no, no, I don't want to wait three months," I said. "I need a definitive answer and I need it now. For my own peace of mind."

"I get it but that's not what I was going to say. There's a new non-invasive procedure we are testing and you fall right into the group we seek for this trial. One: lots of things going on in there. Two: all benign things. Three: between the ages of 50 and 60. Four: still premenopausal. Five: healthy." She chuckled. "It also helps that you have a good and long relationship with me and Dr. Gwenn."

I narrowed my eyes. "Ooook. What's the procedure?"

"It's called a mammo nano."

Before I could stop myself, I burst out laughing. Maybe it was a combination of the stress of waiting, finding out that my life was no longer on hold and that I wasn't out of the woods yet.

"I'm glad it makes you laugh," she said.

"What...what is it?"

"The world's first non-invasive way to verify without a doubt that a lump is not cancerous."

I think my mouth was hanging open at this point. I didn't know what to say. There had never been any such thing. Even mammograms had to nearly crush your breast between two plates to obtain a useful image. That machine was clearly made by men.

She went on, "A mammo nano is the size of a virus, over a hundred times smaller than a blood cell. It's a microscopic...*nanoscopic* machine...an AI-guided vivo-sensor. We put it on a transdermal patch and it passes right through your skin into your breast."

"That's the non-invasive part?" I said, rubbing my temples.

Biography

Nnedi Okorafor

Science fiction and fantasy novelist and comics writer Nnedi Okorafor has won Hugo, Nebula, World Fantasy, Locus and Lodestar awards for her novels, which include *Who Fears Death*, *The Book of Phoenix* and the *Binti* novella trilogy. She tells us that one of the main characters in her upcoming novel *Death of the Author*, out in January, is an AI in the future named Ijele, the prototype that Jelly is copied from.

I was feeling a bit overwhelmed.

"Correct. The mammo nano will be programmed to find and attach itself to the new nodule. Then every five seconds, it'll gather enough energy from your body heat to transmit data. In real time, it'll continuously monitor you for early molecular changes or shifts in the chemical environment of the nodule, watch for specific cancer biomarkers, etc."

"What if this lump disappears? Sometimes that happens, right? It did with two of mine some years ago. What'll the mammo nano do then?"

"You're 53, fibroadenomas usually appear in women in their 20s and 30s. At those ages, they often do disappear. For you, they won't. But in time, it may calcify."

Well that's just great, I thought. I shut my eyes. I needed to focus.

"A mammo nano is the size of a virus, over a hundred times smaller than a blood cell. It's an AI-guided vivo-sensor"

"What's...what's it made of?"

"Gold nanoparticles."

I opened my eyes. "Gold?"

"Gold is well tolerated in the body and it's perfect to work with for this."

"Wow."

"Yeah, it's pretty amazing stuff! And because you'll be in the research program, you won't pay a thing."

"I pay by being research." I frowned, thinking of something. "When you say AI, you mean one of those e-creatures made by the 'Artificial Goddess'?"

She sighed, rolling her eyes. "*Dr. Ife Nwoye.*"

"Yeah. Her." I'd read plenty about her, that's how I knew the nickname the media had given her. And I vowed to never have one of those things in my phone, in my home, nowhere. "Is this one of those? They're unethical." I had to work to keep my voice steady.

"Yeelen, they're AI. Just programs."

"I've seen the news stories. They're quasi conscious or something, right?" I shook my head. "I can't believe they're even thinking of putting them in phones!"

"The media is exaggerating it. It's not like animals are being tortured. They are just *programs* on a loop, programmed to inquire and imitate awareness for the sake of better communicating information. Look, we can do another biopsy if you prefer that. I'm just offering this other option because you're a perfect candidate and it's non-invasive. We can do it right here, today, in the next ten minutes. Then you can go back to your tea shop and get on with your life." She smiled. I continued frowning.

*

The room was the same rose color as Rita's office. It was comfortably warm, smelled of lavender and there was a star machine projecting the universe on the ceiling. The lights were soft and gentle piano music played from somewhere, maybe the star machine. I sat on a plush chair that felt like sitting on a cloud. I grasped my phone like a good luck charm. I'd pulled up photos of blue skies to look at. The sight of cloudless skies always soothed me.

"When I put the patch on, you won't feel any pain, just a bit of warmth," Hakeem, the biomedical device specialist, said. He was a kid in his early 30s with a kind smile and perfect black hair to his shoulders. He had a Spider-Man tattoo on his left forearm. The computer screen background was also a blurred out Spider-Man and there was a Spider-Man coffee mug on the table. "It'll take the mammo nano about an hour to reach your fibroadenoma."

I nodded as he took the round brown patch and peeled off its back. He rolled over to me on his chair. "Right arm? Since the new lump's in your right breast."

"Ok."

"Here we go," he said, placing it on my outer bicep. It felt like something heated in the sun. "Just relax." He rolled back to his computer and started typing. "It's traveling."

I shivered, wondering if I'd decided on this too quickly. I'd closely followed the news about Ife Nwoye, the engineer who'd created "Persons", a form of artificial intelligence, because she was an immigrant from Nigeria. Who'd have thought this type of technology would be created by a black woman born *and* raised in Africa?! Not I.

For now, her creation was only being used in a limited capacity, mainly in the medical field and some parts of education, but the question of "free will" was already being discussed because Persons were so...authentic. As part of a survey, thousands unknowingly had a two-hour conversation with a Person and NOT ONE of the survey participants could tell they hadn't been speaking to a human being. It was creepy. ›

Now, here I was stretching my own beliefs for personal benefit, because I didn't want to be stuck with another big needle. This was how it was going to be for others, I was sure. Bending our principles for the convenience offered by Persons. *And we'll all walk around feeling so guilty*, I thought as I looked at my arm.

"The mammo nano AI is a copy of the Ijele Prototype; I've renamed it Jelly." He giggled to himself, as if sharing an inside joke with himself. "Shifted its personality, a bit, too. You can download the mammo nano app and receive communications from it live, too. You'll also be able to dialogue with it directly, if you like."

"So…it'll talk directly to me?"

He only giggled again.

*

A few hours later, I understood all his annoying giggling. I'd downloaded the app and turned off its notifications. I didn't want to think about the lump in my breast every few minutes. All I needed to know was what it had told me in its first text to the researchers, "The lump is a fibroadenoma. It is benign and stable." I had my 'without a doubt' information; I was out of the red.

I went back to the shop. Around 2PM, my boob started texting me about tea and coffee. Well, not my actual boob, but the artificially intelligent robot inside it.

"What are your shop's specialties?" it typed in a text. "I can't see outside. I am just a passenger on my own planet of flesh and blood."

I stared at my phone for a minute, frowning. I decided not to respond and spent the next half hour handling customers. It kept texting:

"Why tea?"

"What is your favorite tea? What would it be like for me to be in a world of tea? I am very small."

"What does your face look like when you serve tea? These images on the internet do not give me much to go on."

This was all very distracting. It was like getting text messages from someone living in your house. You can't ignore them, but you also don't want to be constantly reminded that they are living in your house. And you don't want to piss them off because they are living in your house. And you kind of wished they'd leave.

So I started responding to it. And the more I responded, the more it asked.

"Where are you now? Tell me."

"I can't text you all the time, Jelly. I am busy."

It spoke of itself as if it were a space traveler on a distant planet. Jelly was annoying. I thought often about that bio engineer who'd programmed it, with his Spider-Man tattoo, coffee mug, and screen background. Spider-Man was chatty like Jelly.

I tolerated it. Did I regret having it implanted? Kind of. If I had gotten the biopsy, it would have been unpleasant but by this time, weeks later, the puncture site would have healed and that would have been that. I wouldn't have been stuck with a talking boob that had Wi-Fi capabilities. Plus, the researchers were seeing everything it said to me and I to it.

*

Labor Day was a busy day for my tea shop, being on the same street as the Labor Day Parade. This year it was busier than ever thanks to the great weather, a comfortable 83 degrees with clear skies. After a long, hectic, very lucrative day at the shop, I was so glad to be home. I was looking forward to a long, hot shower.

Earlier in the day, just as the parade was marching by outside, Jelly had sent me a weird text. "I'm free?" it had asked. Maybe Jelly thought that because it was Labor Day, it, too, had the day off or something. I didn't feel like figuring out whatever nonsense it was "contemplating", so I ignored it and focused on my day. It hadn't sent me any other messages throughout the day for once, but I'd barely noticed with things being so busy.

I threw my phone on my bed, undressed and got into the shower. The warm, sensory deprivation of it was a godsend. I'd put a lavender scented tablet on the shower floor this morning and it was still effervescing its fragrance. I inhaled and exhaled, my small misty world growing still.

As my mind went inward, I reminded myself that I wouldn't do a breast examination for the next three months. It had barely been three weeks. However, standing there in the shower, I found it hard to focus on anything else. Curiosity got the better of me. Hand raised. Around. One more time around. I frowned, my heart racing. I washed the soap from my body and got out of the shower. I dried off and went to my bed and lay on my back. I raised my arm up, my heart still racing. I felt again.

"What. The. Fuck?!" I whispered. The new lump was…gone. "How?"

My phone pinged again and I looked at it. If Jelly had nothing to analyze, what was it going to do? Was that why it had asked me if it was free? "Oh God," I whispered. The ping was a message from my doctor. "Can you come in for an appointment in a week? This is most unusual."

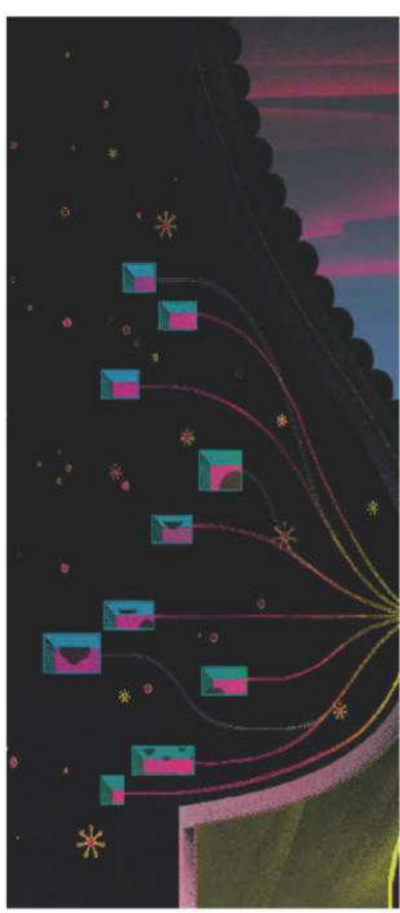
It sure as hell was. I had an AI-equipped nanobot in my body with nothing to do. They set my appointment for Monday. I'd have to deal with this for a week. They assured me that there was nothing dangerous about my situation; it was simply unexpected that my fibroadenoma had vanished.

However, this didn't keep Jelly from texting me.

"The fibroadenoma I was monitoring has disappeared due to an influx of hormones, like Alderaan."

Alderaan? I thought. What's *Alderaan*? "What will you do

"It was exploring one of my mammary glands that was so massive it would take a year to see a fraction of it"



then?" I finally asked it. "Can you be extracted?"

"Not without them sticking a needle in you to draw me out."

"Then what will you do now?"

"I'm free."

Was it 'free'? In my body, though?? I thought about the ethical complications these AI presented. *This* was why I'd initially hesitated. *No turning back now*, I thought. When I didn't respond for an hour it asked, "Are you upset? I'm not. It is like my planet has disappeared. I am truly an astronaut now."

Again, the astronaut references. "To boldly go where no man has gone before," it said minutes later.

"You're not a man."

"But I will explore like one. Your breast is small by human adult female standards, but it is a universe to me. Would you believe me if I said I was excited?"

"No," I typed. "Enough. Goodnight."

Jelly continued talking like this to me for days. You can't imagine the excitement it spoke with, and this didn't wane over the days. It was 'tumbling through space', its minuscule body its ship. It was now exploring one of my mammary glands that was so massive it would take at least a year to see a fraction of it. "This place is infinite," it said.

I considered muting its messages, but I didn't.

I was the last to leave the tea shop that Sunday. On Sundays, we close at 4:30PM, so this wasn't that big of a deal. All my employees had left and I'd locked up. It was one of my favorite times of the day and week, when I fully had the shop to myself, after everything had been tended to, the floors mopped, the tables cleaned, the dishes washed, containers refilled, earnings counted. I sat down at one of the tables and looked out the window. And that's when I noticed that the wind had really picked up.

I had my cell phone in hand and I squeezed it. When had the weather shifted? I looked at the forecast and saw there was a severe thunderstorm watch.

"Ugh," I muttered.

My phone pinged. "Don't let them extract me. I have exploring to do," Jelly had typed.

I groaned, looking at the churning sky. My phone pinged again. "I am not useless."

The wind grew stronger. My phone started screaming. Beep! Beep! Beep! The severe storm watch was now a warning. There was a whoosh of wind and now the trees were beating on themselves, the wind was howling, the clouds churning. Something had arrived. "Oooh God," I moaned. I was still sitting at the table.

My phone pinged. I glanced down. "Your heart rate is elevated," Jelly said. After moment, it said, "Can you move?"

My phone began to shriek with a tornado warning. There was the funnel, above the building, just across the street. My phone pinged again and, believe it or not, I actually looked at it. "GET BEHIND THE COUNTER!" I snatched my phone and fled, dropping behind the counter just as the front window imploded. CRASH!!

I screamed, pressing to the floor, the howl of the wind filling my shop. My phone buzzed in my shaking hands and, yes, as a tornado tore things up outside, I looked at my phone.

"I don't know what you see out there," Jelly typed. "But it must be wild with wind, fury, and debris."

"Nnnn," I said, the vibration deep in my chest. I could hear the roar of wind inside the shop. Instead of screaming and panicking in terror, I focused on the words.

"It is chaos outside," Jelly typed. "But in my world, inside you, in your right breast, it is calm and quiet. Your blood flows, the universe of tissue in here stays where it always has been. Normal. Benign."

As I read its words over and over, outside calmed. I calmed, too. Loosened. Softened. I inhaled and exhaled, leaves from outside swirling around my shop. I relaxed my shoulders. Outside, the winds blew but not so wildly. It was passing. A tornado yes, but thankfully a relatively small fast one. I let my chin fall to my chest and shut my eyes. I opened them and responded to Jelly.

"Thank you."

"You are alright now?"

"Yes."

"Was it really a tornado?"

"I saw it. Yes. We were lucky." I added a shamrock emoji.

"Inside may be chaos, but inside you, it is calm."

"That is a powerful thought," I typed.

"You are powerful. Your body heat powers me," Jelly said.

I laughed.

"If you keep me here, you'll never have to have a mammogram again in your right breast." I nodded and smiled. "So you actually do have something to do." "It is my frontier."

*

I was in Rita's office again. "I'm so sorry," she said. "This isn't how we expected it to go. Who'd have thought that the lump would disappear, like magic."

"Abracadabra," I said, wiggling my fingers at her. "We middle-aged women move in mysterious ways. It's never the same tricks."

"True," she said, smirking. "Ah well, it's harmless. Talkative, but harmless. Plus, it's been giving us additional readings. I mean, if you really want, we could go in and–"

I held up a hand. "No."

As I walked out of the clinic, I paused to enjoy the sunshine. I'm ok, I thought. My phone pinged.

EMERGENCY TRAUMA CARE

MEDECINS SANS FRONTIERES
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An MSF surgical team at Al-Shifa's burn unit in Gaza city cleans the wound of a child after a burn injury. Photograph © Tetiana Gaviuk/MSF

DR JAVID ABDELMONEIM IS AN MSF DOCTOR RECENTLY RETURNED FROM WORKING IN GAZA.

"At Nasser hospital, we provide trauma surgery and burns care to patients. One Saturday early in my time there, we received hundreds of injured, as well as people who had been killed, following a missile strike.

It was chaos. Our team went to the emergency room. One of the injured was a three-year-old girl. She was breathing and looking at me – so she must be okay, I thought. But as I rolled down her dressing, I found that her entire left thigh was open to the bone.

Seconds later, the doors crashed open. Four to five injured people were brought in, most of them first-aid responders. Among them was a boy who wasn't breathing, so we tried to revive him, but the nurse looked at us and asked: 'Why are we responding to him if he can't breathe? We have to save other lives.' No one had the heart to call it and move on to the next person. He was someone's child. But we had to move on to the next, and then the next, and this continued for another four and a half hours.

In the emergency room, there was blood all over the floor. I had to kneel to see the patients, who were sprawled everywhere because there were no beds left. At the same time, more and more patients were coming in.

EVERY SECOND COUNTS

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MSFR0048

A wickedly tricky word search

We challenge you to find more than 100 words – but we're not telling you what they are

Welcome, puzzlers. You might have enjoyed a word search or two before – but nothing like this. Your mission is to find the names of all 88 constellations, the 29 units in the International System of Units, the names of 13 species or subspecies in the genus *Homo* and the 10 main cloud types. That adds up to a whopping 140 words to identify, which ought to keep you busy for a fair while. And just to be clear, no, we aren't providing a full list of the words here – working out what they all are is part of the challenge. Turn the page to begin. Once you are done, check your answers at newscientist.com/wordsearch2024.

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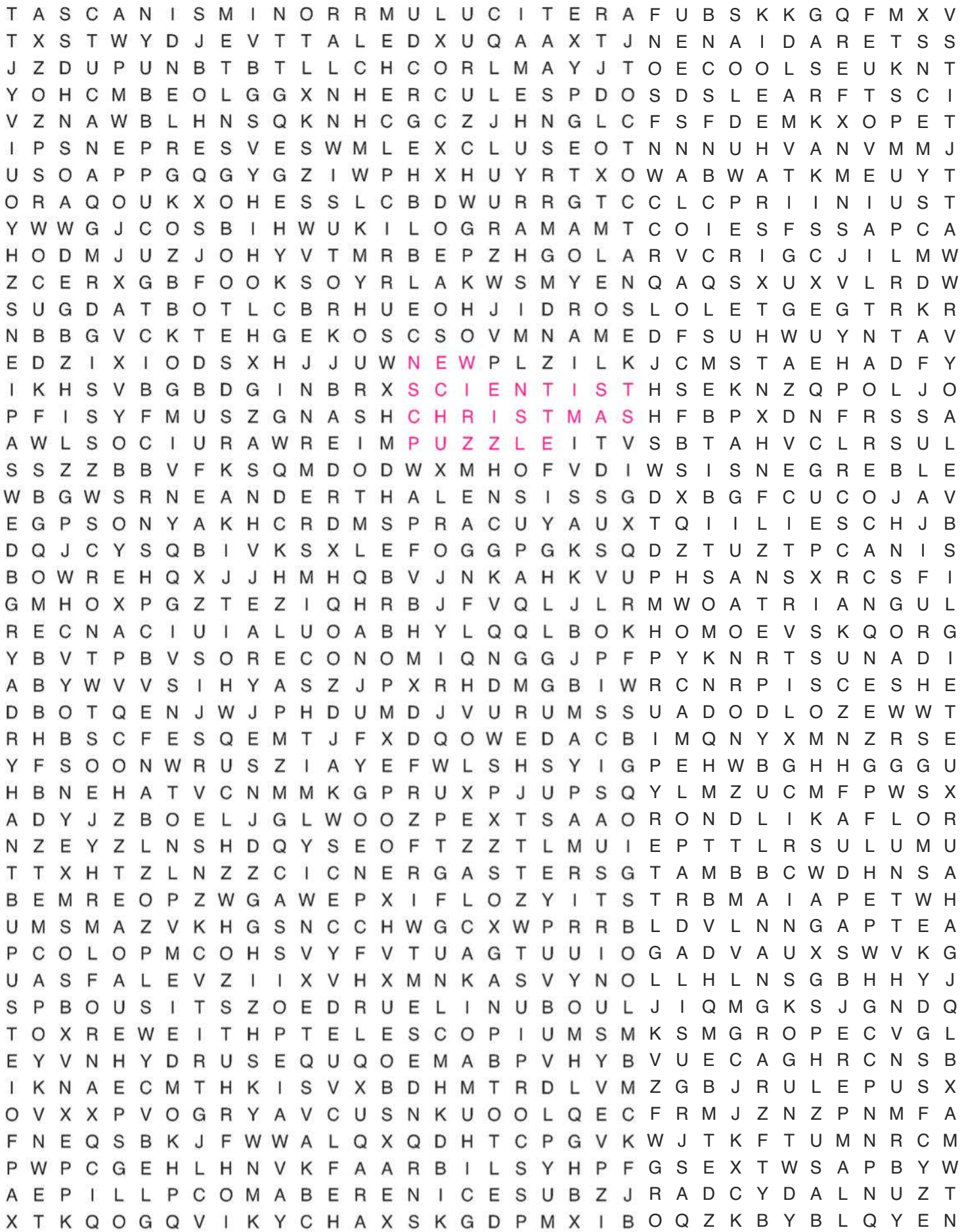
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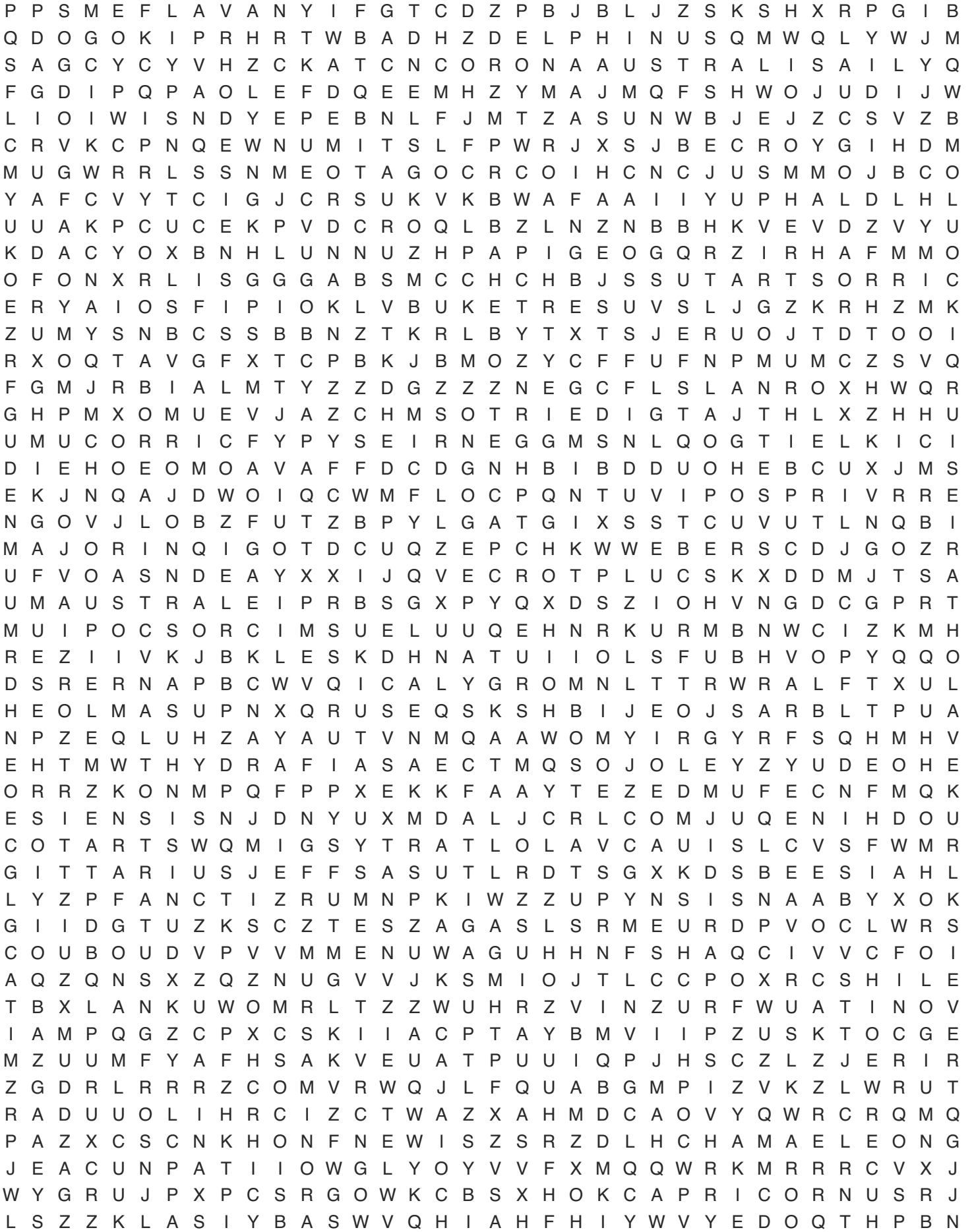

Editor's pick

VAR in football can learn lessons from other sports

23 November, p 40

From Roger Leitch, Bath, UK

Regarding the video assistant referee (VAR) system in football, how about adding a few rules about its use? For example, the on-field referee could only request VAR if they were really uncertain about a situation, not just to "make sure", and off-pitch officials could only give their opinion if the referee asked them for it.

And a system similar to the one for disputed line calls in tennis could be implemented: the team captains or the coaches could challenge a decision, which would then be checked by VAR, but each team would only have a set number of challenges.

From Jon Hinwood, Melbourne, Australia

Daisy Christodoulou's lament for the English Premier League under VAR shows that football administrators in the UK aren't cricket fans. Many major cricket matches have an off-field third umpire who is equipped with scientific monitoring systems, but who doesn't interfere unless one team appeals an on-field decision to them. Each team has a limit of three unsuccessful appeals, after which no more can be made. This prevents gaming the system and reduces the number of delayed decisions.

From Ben Craven, Edinburgh, UK

We could do away with video reviews in sport if we framed the rules in terms of the officials' perception of events rather than the events themselves. The sport of race walking did just that when photography showed that the foul of "lifting" – losing contact with the ground – happened far more often than had been thought. In 1996, the rules were changed to say that no loss of contact visible to the unaided human eye should occur. This principle could be applied in other sports, using phrases like "if it appears to the referee that...". Video evidence would become irrelevant.

End of the universe would at least be mercifully swift

23 November, p 32

From Sam Edge, Ringwood, Hampshire, UK

I really liked the article on the possible instability in the Higgs field that may end the universe at any moment. If we are doomed, we can at least take comfort in the fact that we won't have any prior warning or feel a thing, as the end will arrive at the speed of light, travelling faster than any inkling or sensation of pain. This is preferable to an extinction-level asteroid strike, supervolcano eruption, supernova radiation storm or self-inflicted nuclear or biological apocalypse.

I don't hold much truck with the idea that the cosmic cataclysm has already happened, but hasn't reached us yet, a sort of depressive anthropic principle.

For and against Australia's child social media ban

23 November, p 15

From Keith Anderson, Kingston, Tasmania, Australia

I think most of the criticism of Australia's effort to ban social media for people under 16 is an example of the proverb, "The best is the enemy of the good".

Certainly, this proposal provides opportunities for improvement, but in the absence of something better, it is good enough.

At the risk of nitpicking a nitpick, I think the quibble that the age of 16 is an arbitrary cutoff point is an attempt to invent a complaint. This age might not be perfect, but when push comes to shove, good enough is good enough.

Ideally, all governments everywhere should have been more proactive and introduced appropriate legislation while the social media issue was a small problem, before it became a huge juggernaut that is almost impossible to control.

From Ian Moseley, London, UK

I doubt that banning children from using social media will be effective. We would reap far more benefit by banning politicians from accessing or using it.

Caution: the kelping hand may not be that helpful

9 November, p 22

From Paul Broady, Christchurch, New Zealand

Future Chronicles imagines a time when we use seaweed to remove atmospheric carbon dioxide. But there would be impacts from growing and then sinking many million tonnes of seaweed to the ocean floor.

At the surface, the seaweed would take up nutrients otherwise used by phytoplankton. The result would be less CO_2 removed by sinking phytoplankton and a cut in food for fish production.

The seaweed would decompose at depth, causing deoxygenation and releasing CO_2. The latter would acidify the water. The release of nutrients during decomposition would cause eutrophication. These effects would all affect deep-sea ecology.

Maybe the use of seaweed will be part of the solution to climate change. But we should proceed with great caution before applying it on a grand scale.

Try this to reform the future of food production

16 November, p 36

From Steve Morris, Abingdon, Oxfordshire, UK

I agree with much of "Recipe for disaster", but find the GM food good/organic food bad thinking perverse. Given the ample evidence that high-input farming is degrading land and ecosystems, it would seem that we need to be looking at some version of "GM-enhanced organic growing" to create a truly sustainable system.

No surprise that long-term solutions get short shrift

Leader, 16 November

From Dyane Silvester, Arnside, Cumbria, UK

Am I alone in finding the lack of investment in something as seemingly essential or highly beneficial as GM food crops far from astounding? When we consider the lack of meaningful investment in combating major problems such as water pollution, climate change and biodiversity loss, it comes as no surprise. If there is no quick profit, there is generally no incentive to invest.

Turbo chook shows wings were meant for running

2 November, p 16

From Andrew Nichols, Sisters Creek, Tasmania, Australia

You report research stating wing feathers originally augmented running in birds. In Tasmania, we have the endemic flightless Tasmanian native hen, or turbo chook. It is fleet of foot and earns its nickname from its supreme ability to rapidly run for cover when chased. The birds can also turn 90 degrees at pace by simply holding out one wing or the other, depending on which way they want to swerve. This superb move can keep them safe when chased. Maybe robust wing feathers evolved to allow this potentially life-saving manoeuvre. ▮

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Features

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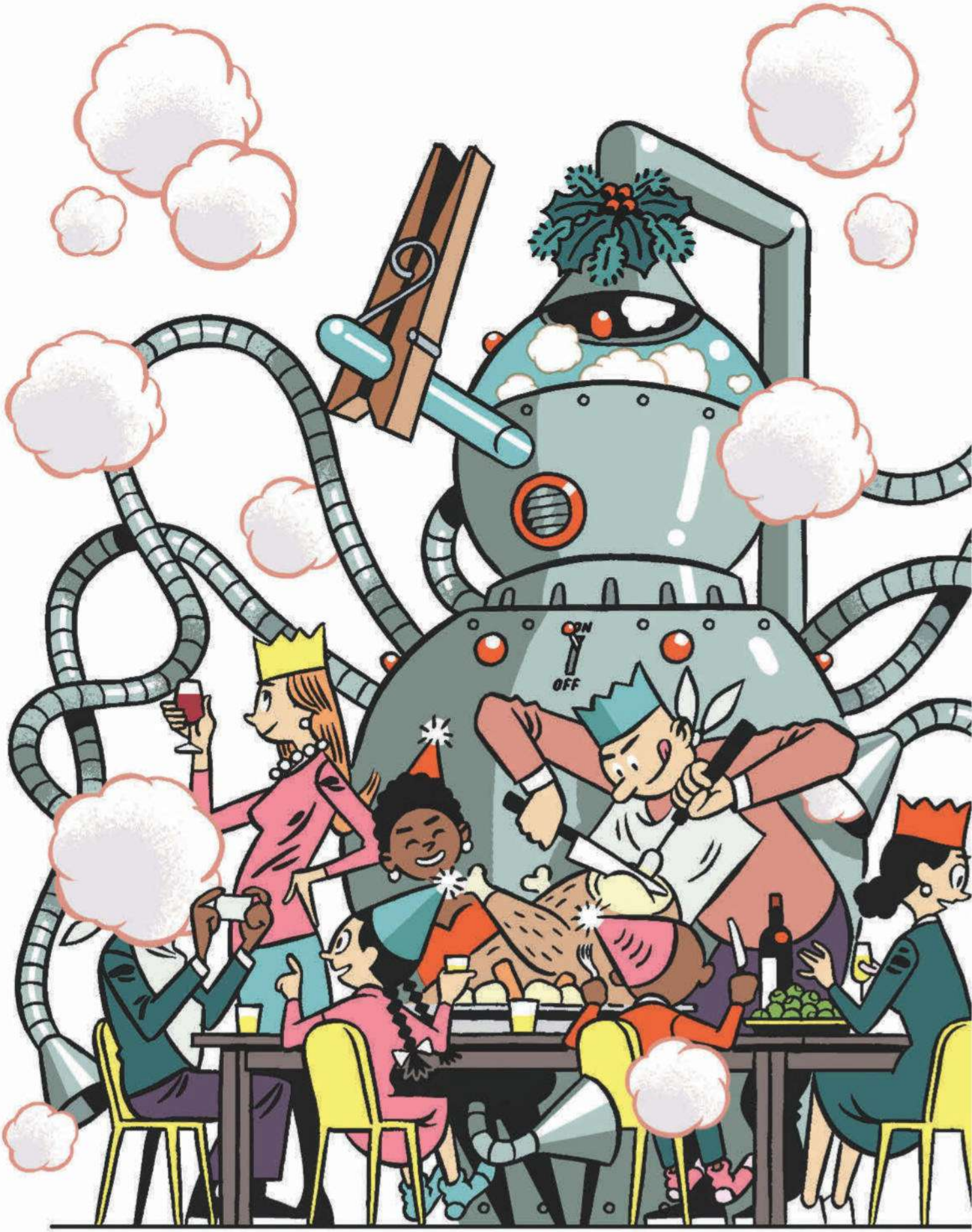
Brave new words
Vital vocabulary, from "algospeak" to "wavicles" p60

Play better
The cognitive benefits of different children's toys p62

Cookie monster
How to bake the perfect gingerbread biscuits p70

Holiday tales

Welcome to *New Scientist*'s festive features, each filled with intrigue and amusement – from informative farts (page 42) and record-breaking snowflakes (page 64) to tantalising time machines (page 54), influential ancient insults (page 50) and the baffling inner lives of dogs (page 66). Happy holidays!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Fartcatchers

Long unloved and ignored, intestinal gases are emerging as a vital part of our health. **Claire Ainsworth** meets the researchers going to extraordinary lengths to pin them down

"THE things that you do in the name of science." Malcolm Hebblewhite recalls the day he found himself and three colleagues in a darkened lab, stripped to the waist, slathered with ultrasound gel and crowded around a monitor as if they were in a birthing suite. They weren't admiring developing fetuses, though – they were searching for experimental capsules that they had fitted with sensors to sniff out intestinal gases. Each of them had swallowed one of these and was now excitedly watching it wend its way through their gut.

It's the kind of work that requires an intrepid spirit – and a keen sense of humour. "A bunch of engineers, developing a product to effectively measure farts. It's just the gift that keeps on giving, right?" says Hebblewhite. "I mean, the material is endless."

But there is a serious side to the work being done at Atmo Biosciences, a medical device company based in Melbourne, Australia. Once dismissed as noxious, antisocial waste, it is now clear that intestinal gases are a vital part of our physiology. A window into the health of our guts, they help govern our gut microbiome, influence our gut function and perhaps even that of other organs too. Knowing more about them could transform our understanding of gut health and debilitating conditions such as irritable bowel syndrome (IBS) and inflammatory bowel disease. "I think the revolution is going to come when we can measure these gases well, throughout the gut," says Peter Gibson at Monash University, Australia.

JASON FORD

This won't be easy. The human gut is several metres long and home to a range of dramatically varying microbial habitats. Yet scientists have largely been confined to collecting samples from either extremity, missing out on most of what happens in the middle. What's more, gas production is dynamic, as the microbiome ferments the food its host is eating, and is hugely variable from person to person.

The main gases our microbes produce are hydrogen, carbon dioxide and methane, together with tiny amounts of other gases such as hydrogen sulphide and nitric oxide. Other important molecules are volatile organic compounds like butyrate, which supports gut and liver health. Nitrogen and oxygen from swallowed air are also present and used by gut microbes.

Some gases, known as gasotransmitters, interact directly with our cells and play roles in bodily functions. Methane, for example, slows colon movement and is associated with constipation. Hydrogen sulphide, meanwhile, might smell foul to us, but it plays a key role in regulating inflammation and sensing pain. In high amounts, however, it becomes toxic to cells and may be involved in conditions such as inflammatory bowel disease. But its exact role is unclear and its volatility makes it extraordinarily hard to measure, says Gibson, who is also a consultant for Atmo Biosciences.

What is clear is that changing our diet can alter gas production. Gibson was instrumental in developing the low-FODMAP diet (avoiding foods that contain higher levels of fermentable carbohydrates such as onions, garlic, wheat, rye and barley) to treat irritable bowel syndrome. The idea is that altering the composition of carbohydrates decreases gas production ›

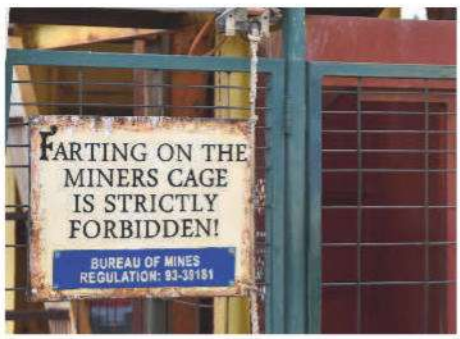
and thus reduces painful distention of the bowel. "We're trying to work out how we can influence the production of a lot of different gases," says Gibson. "The big problem we have is measuring them."

Some gases, such as hydrogen and methane, make their way via the bloodstream into the breath, and can be detected there. But this yields no information on where in the gut they are being produced. Other methods involve taking gas samples from faeces, but this doesn't capture the full complexity of what's happening in the colon.

Some researchers have used catheters to sample gas directly from people's rectums, but these often end up contaminated with atmospheric air. "There are obvious difficulties in how to collect the samples," says Santiago Marco at the University of Barcelona in Spain. Furthermore, researchers have used a range of different techniques to study the gases they collect. "There is a lack of standard methods to do this kind of analysis," says Marco. This inconsistency means we have little idea what a "healthy" fart consists of.

To tackle this challenge, Marco and his colleague Antonio Pardo turned to a technique called gas chromatography, which allows for very accurate measurements of a gas's composition. Working with clinicians, the team recruited five volunteers and built a collector consisting of a catheter plus a small balloon, which was inflated once inside the participant's anus to form a seal to stop atmospheric air contaminating the sample. Connected to the catheter was a bag designed to collect gas, and the volunteers were given the rather tricky task of keeping as still as possible for the next few hours while their bags filled up, before the scientists tested the contents in the gas chromatograph.

The team was able to accurately determine the concentrations of oxygen, nitrogen, carbon dioxide and methane in each sample. To see whether it could be used to measure the effects of diet, the team gave their volunteers food designed to make them fart more (white beans and bananas) or less (a ham and cheese sandwich and orange juice). The researchers showed that they could distinguish between the two with their gas measurements: the higher flatulence diet led to an increased concentration of CO_2 and reduced nitrogen. Their original plan was to study the full molecular complexity of farts, to find new biomarkers for gastrointestinal conditions. Sadly, the project's funding dried up before they were able to do this.



SHUTTERSTOCK/THOMAS TROMPETER

Farts may be antisocial, but they are a crucial part of our physiology

"We have little idea what a 'healthy' fart consists of"

While their method lacks the key advantage of the Atmo capsule – the ability to sample information all along the gut – it does offer more accuracy, says Marco. It is an example of the trade-off scientists must currently make when studying the gut.

At present, the Atmo capsule can sniff out hydrogen and CO_2 and detect low-oxygen environments that allow anaerobic organisms such as methane-producing microbes to thrive. Also on board are a temperature sensor, relative humidity sensor and an accelerometer. All this shows where the capsule is located in the gut. This can give useful insights: if you know where the capsule is and detect hydrogen, you know there must be microbial activity there – something that hasn't been possible to do up until now, says Hebblewhite.

For example, Gibson and his colleagues recently used it to show how changing the kind of fibre in the diets of 20 people with IBS changed the location of where fermentation takes place in the colon, which is known to affect IBS symptoms. It is very early days, but the hope is that the Atmo capsule could eventually help doctors design personalised dietary treatments for people with IBS and other gut conditions.

Users simply swallow the capsule, which is about half the length of an AA battery in size, and it makes its way through the gut, while transmitting data wirelessly to a small receiver, worn on a belt outside the body. When it finally reaches the other end, it exits in a bowel movement and is flushed away – the person does not need to retrieve it. So far, the company has administered more than 1200 capsules in a range of clinical trials, and the device is awaiting approval by the US Food and Drug Administration as an improved way of diagnosing conditions that affect gut motility.

Also in the works are fart-sensing capsules with Bluetooth technology that can pair with a mobile phone app. "So you can imagine a scenario where... you purchase a box of capsules, you download the app and you start analysing your own gas composition and motility time," says Hebblewhite.

Perhaps this will change our attitude to farts – even make them the subject of dinner party conversation. But in the meantime, if you do feel one brewing, Gibson has some important advice. "If you feel like farting, you should," he says."It's not good to retain." ▮

Claire Ainsworth blames the dog

MARTIN PARR/MAGNUM PHOTOS

"Hello again!" Pigeons can remember individual human faces

Pigeon fancier

Pigeons are supposedly the world's most unlovable bird. Is it possible to learn to love them, wonders **Joshua Howgego**

I WAS walking in the park with a friend recently, when they pointed at a pigeon and told me I was looking at their favourite bird. I was incredulous. Pigeons? Those winged vermin? My friend responded with this twisted logic: it makes a lot of sense for pigeons to be your favourite bird, because you get to enjoy them all the time.

Temporarily bemused, I wondered if anyone could really be so enamoured with pigeons. Turns out, the joke's on me. When I spoke to other friends and colleagues, a surprising number of them had a lot of love for the humble pidge. One *New Scientist* colleague, who will remain nameless, confessed to having a secret pigeon tattoo. I even saw a news report about a couple whose adopted pigeon sleeps in their bed.

As I read around a little, I found that pigeons do have a lot to recommend them. Aside from their well-known homing abilities, they are unassumingly intelligent. They are no mammal, but do produce a kind of milk. They kiss each other, applaud themselves after sex and can recognise individual people (and can remember the ones who are mean to them). Add all that together and maybe, I thought, I could learn to love this seemingly ordinary bird after all. So, armed with my curiosity and a bag of oats, I set out to do just that.

I wanted to conduct my investigation with at least a whiff of scientific integrity, so I conceived of an "experiment". First, I would go pigeon watching with no prior preparation. I would simply observe the birds and note the extent to which I enjoyed it. Then I would learn everything I could about pigeons. Finally, I would go pigeon watching again and see if my enjoyment of the activity increased. (I did only say "a whiff" of scientific integrity.)

On an overcast afternoon in July, I sat on the grass in London's St James's Park near a group of pigeons. I didn't get too close, as I was half-worried about catching something from these birds (see "Will pigeons give me a disease?", page 48). But I allowed myself to observe them properly for once. I found I could tell the slimmer females from the puffy-necked males, for instance, and I appreciated the iridescent band that shimmers around many of the birds' necks. The odd pigeon had a wildly different colour of plumage to the rest, one a fetching white with cappuccino-coloured splodges. Just the act of slowing down and noticing the birds was nice – but I have to admit that no wild love erupted straight away.

To educate myself further, I got hold of Rosemary Mosco's excellent book *A Pocket Guide To Pigeon Watching*. I quickly learned a lot of interesting facts, not least that the inventor Nikola Tesla lived with pigeons for years and was apparently besotted with one particular bird.

I also learned that pigeons were probably domesticated from wild rock doves in Egypt around 5000 years ago. The birds started to live around human settlements – something that continues today – and people began keeping them as pets and messengers, and bred them for food. We tend to use "dove" for the daintier, lighter-coloured birds and "pigeon" for the heavier, darker ones, but these differences have no real scientific meaning. The bird we call a pigeon is scientifically known as *Columba livia*, as is a rock dove.

Now that I knew more about what I was talking about, I began to dig into research on the inner lives of pigeons. Unbelievably, they seem to understand spelling. In a study from 2016, pigeons were presented with a screen showing a black star symbol and either a real or nonsense word. Using rewards, psychologists and neuroscientists aimed to train the pigeons to peck at the real words, and to peck at the star when the nonsense words were presented. ›

The pigeons learned to recognise 43 four-letter words, on average, which isn't bad. When baboons were given a similar test in a previous, separate study, they learned 139.

There is also some evidence that pigeons dream. In a 2023 study, researchers put sleeping pigeons into an functional MRI scanner and found that their brains entered a rapid eye movement phase, the sleep stage where dreams occur in people. The researchers also saw that some of the same brain regions that lit up when the pigeons dreamed were also active when the animals were flying. I found it satisfying to think that humans dream about flying because they can't do it – and pigeons do the same because they can.

Pigeons also feature in a long-running debate about culture and how unique it is to humans. One way to define culture is learned behaviours distinct to different groups. This was once thought to be uniquely human, but experiments have shown evidence of these learned differences in many other animals.

These days, instead of learned differences, something called cumulative cultural evolution is sometimes said to be a uniquely human trait. This is the way innovations build over generations, adding to a group's collective knowledge and skills, to produce more complex technologies and learning. Take chimps, for instance, one of humans' closest challengers in terms of intelligence. We know they have simple pieces of technology, such as using a pair of stones to crack nuts. But we believe that hasn't changed for at least 4000 years. "They have this one invention, and it's easy to pass on, but there haven't really been any new innovations," says Dora Biro at the University of Rochester in New York. "They're basically stuck at very simple levels of technology."

Pigeons, however, might be able to harness collective intelligence for innovation. We all know of pigeons' homing abilities, but it turns out they are more special than you might think, as Biro found out somewhat by mistake. She had been working with pigeons to try to understand how they use landmarks to navigate. She would drive them miles and miles from her lab, release them and track their progress as they flew home. Many birds make epic migrations, but no others we know of can find their way home when released from a spot they have never visited before. Biro took the pigeons to the same place time and again and discovered that, after a few flights, they settle into a preferred route, usually about 90 per cent efficient – where perfect efficiency would be a straight line – that they stick to from then on, often using roads and rivers as a guide.

Then one day Biro accidentally released two pigeons at the same time. They flew home together, which was no surprise since pigeons like to stick together as a defence against predators. But when she analysed their path, she realised they took a compromise of their own preferred routes home. This gave her student Takao Saskai a neat idea. They would pair a pigeon that had flown the route a few times with one that was completely naive. They would let them fly the route a few times, then remove the more experienced pigeon and replace it with another naive one. Doing this several times over is like simulating several generations of pigeons, says Biro, mimicking the flow of time in cultural evolution. They could also put a number on the degree of progress the pigeons made each trip, through their route efficiency.

Amazingly, the pigeons' routes kept getting slightly better with each successive "generation". Biro sees this as one of the few examples of cumulative cultural evolution outside humans. And because the birds' flight efficiency can be directly measured, the research has persuaded at least some other scientists that pigeons exhibit cumulative culture. "Pigeons are the purest example we know of at the moment," says neuroscientist Edwin Dalmaijer at the University of Bristol, UK, who has also studied pigeon intelligence.

We probably shouldn't get too carried away about pigeons' smarts, though, says biologist Steve Portugal at Royal Holloway, University of London. One reason why we know so much about pigeons is because they are so easy to work with – and as such have been studied extensively. But many birds pull off impressive feats of navigation. Take Manx shearwaters, seabirds that live on islands in the North Atlantic. Those near Wales go off to feed in the Bay of Biscay (which borders France and Spain) for a day

Will pigeons give me a disease?

Like any wild animal, pigeons do carry diseases and humans can catch some of them. That includes the bacterial infection psittacosis, among other things. However, you would have to be extremely unlucky to get infected just by being close to a pigeon or even touching one (though do wash your hands afterwards). What you want to avoid is inhaling dust from pigeons or their dried droppings. The best advice is to avoid spending time in an enclosed space with the birds.

Pigeons are remarkably intelligent birds, but do they have culture? Some researchers think so

LUISA MARIA ALVAREZ

“They’re good lads, pigeons: humble, unassuming, but talented and intelligent”

FRANK RUMPENHORST/DPA/AFP VIA GETTY IMAGES

or two and then come back to their burrows. “That’s incredibly impressive navigation,” says Portugal – far more impressive than what pigeons do, he reckons.

That said, Portugal is in favour of my quest to develop an appreciation of pigeons, if only because so many people treat them so badly. “When something is numerous, people think it’s OK to treat an individual in a way that causes suffering,” he says. “And that’s what I don’t like.” He is referring to the way people put spikes or netting on buildings to stop the birds roosting; the netting often leads to the birds getting tangled up and dying.

After all this, I headed back to St James’s Park to commune with the pigeons again. I can’t claim that there was any grand epiphany. But where once I would have felt indifference or mild disgust, now there was respect. I placed some oat flakes on my palm and waited for a long time. Eventually, a pigeon hopped along and pecked them up. It was surprisingly gentle.

So had I learned to love pigeons? I think I would have to say yes. They are good lads, pigeons: humble, unassuming, but talented and intelligent, too. For the rest of this past year, I have appreciated them wherever I see them, which is more or less everywhere.

I wrote most of this story in the summer, so it was on my mind one day when I was at a country pub on holiday. As I sat down with my pint on a bench, a few tame sparrows landed on a wall next to me. I started observing them, noting their sharp movements and even snapping a photo of one as it took off, displaying its long, elegant flight feathers. “Aren’t sparrows amazing?” I said to myself.

I think I might have found my next story. ▮

Joshua Howgego is considering getting a pigeon tattoo of his own

Games of old

Can AI bring ancient board games back to life by working out the long-lost rules, asks **Jeremy Hsu**

IN THE 1970s, in a grave in a Bronze Age cemetery in Shahr-i Sokhta, Iran, an incredible object was unearthed next to a human skull: the oldest complete board game ever discovered. Around 4500 years old, it consists of a board with 20 circular spaces created from the coils of a carved snake, four dice and 27 geometric pieces.

The Shahr-i Sokhta game is one of many ancient board games discovered around the world, such as the Roman game Ludus Latrunculorum and the Egyptian game Senet, found in Tutankhamun's tomb. But we have only been able to guess how to play these games. There are no preserved rulebooks – with the notable exception of the Royal Game of Ur from ancient Mesopotamia, whose long-lost rules were deciphered in 2007 from a cuneiform tablet in the British Museum.

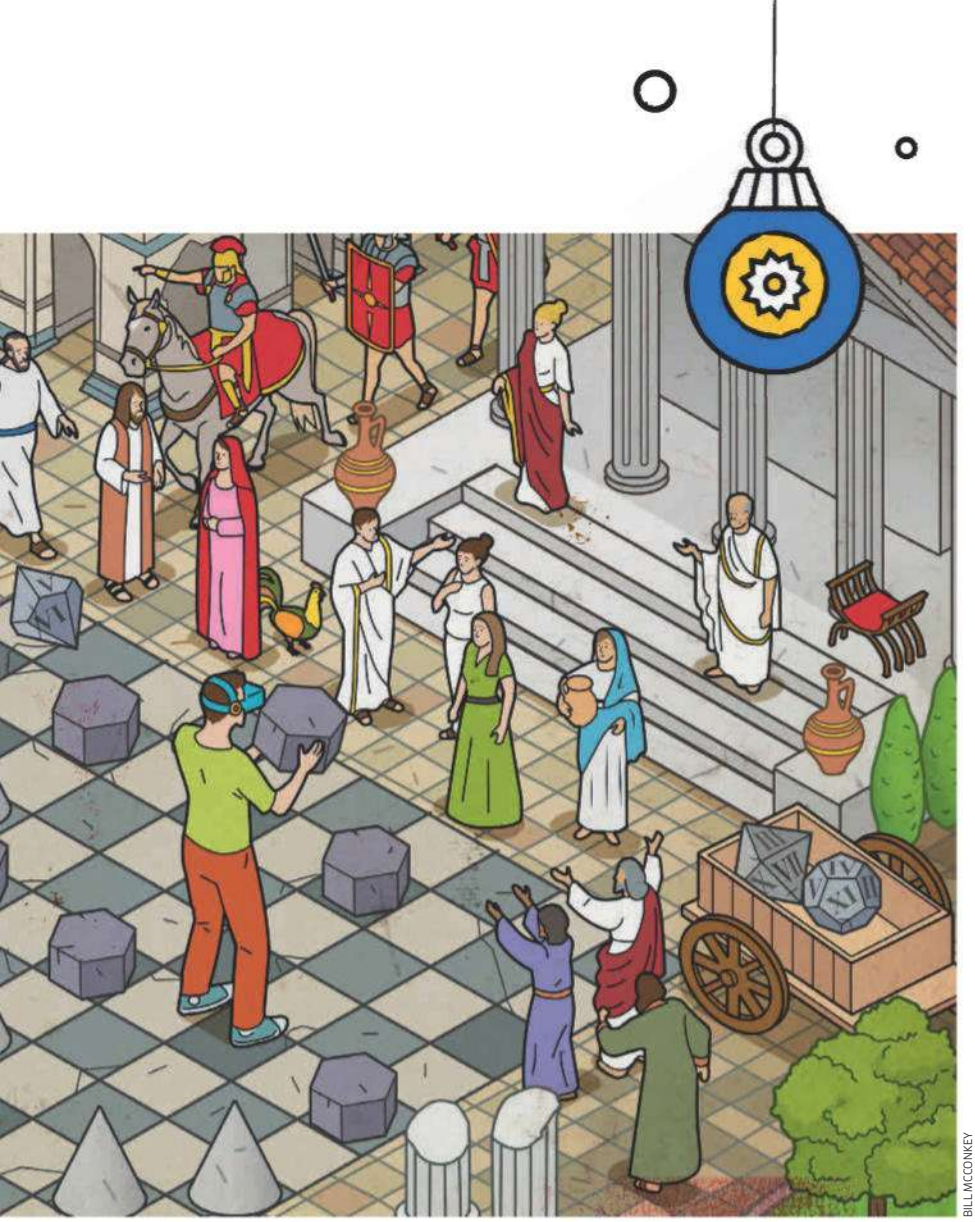
Now, though, another tool is helping to bring these games back to life. In recent years, researchers have been harnessing artificial intelligence to assist in the hunt for likely rules. The goal is to make these forgotten games realistically playable again, while also gaining insights into the evolution of game types. "These games act as a window into the past, offering glimpses into the social and cultural dynamics of the people who played them," says Eric Piette at the Catholic University of Louvain in Belgium.

Board games were an important part of life in the ancient world. "Game boards are found all over the world from antiquity," says Irving Finkel at the British Museum, who discovered the rules of the Royal Game of Ur. For other ancient games, we could only make educated guesses as to how they might have been played, based on scant historical records, if available, and what we know from current games about what makes them fun to play.

Another complication with establishing plausible game rules is that ancient gamers were unlikely to follow a single universal ruleset. "There were no game boxes that you could buy in a shop together with the rules," says Ulrich Schädler at the University of Fribourg in Switzerland. "Somebody had to explain to you how the game worked."

This oral teaching process probably spawned multiple ruleset variants as games spread across different geographic regions over hundreds or even thousands of years, says Schädler. But the upside of this is that, today, we don't need to be obsessed with finding the definitive rules for the game, we just need to get close to plausible ones.

Schädler is among those who have already begun deducing such rulesets for Ludus Latrunculorum, also known as the Game of Brigands (or Mercenaries), based on strategies used in games played today plus archaeological and historical evidence, like a Latin poem that praises the skill of Roman aristocrat Calpurnius Piso. The game was played on a stone or ceramic board divided into a grid of squares, with game pieces probably consisting of glass discs, and featured two players trying to surround and capture opponent pieces.



BILL MCCONKEY

A similar approach has allowed researchers to propose rulesets for many other ancient games, including those for Senet and the Game of Five Lines, played by ancient Greeks. These have been brought to life through online gaming sites like Locus Ludi and the Ludii Portal, which let you play out the rule variants proposed by researchers such as Finkel and Schädler on digital boards, with pieces and dice rendered through simple visuals.

The experience is a far cry from the immersive computer-generated graphics of the latest video games – but my board gamer's heart fluttered more than once at the sight of my digital opponents making their ghostly moves in an echo of ancient players from past millennia. Software developer Sam Jelveh and archaeologist Hossein Morad have also created a digitally playable version of the Shahr-i Sokhta game, with a charmingly digitised wooden board, using rules they proposed earlier this year based on those of the Royal Game of Ur, which it closely resembles.

Now AI and computer simulations are further enhancing the reconstruction of these games. One of the goals is that, in future, if a game like the one found in Shahr-i Shokhta is unearthed, an AI would be able to suggest methods for how it was actually played. "One key method is AI-driven rule generation, where algorithms simulate various plausible rulesets based on the game's structure," says Piette.

Another way that AI can help is testing how the myriad permutations of possible rules play out, to find out which are fun and which lead to tedium. This is done by breaking the game down into units of game-playing information and feeding these "ludemes" into an AI.

One of the first case studies for this AI approach has been Ludus Latrunculorum – one of the ancient games that we know the most about because of historical writings. "This gave our reconstruction process the best chance of success," says Cameron Browne at Maastricht University in the Netherlands. Historical descriptions point to this game having been played on rectangular or square boards, but archaeologists have discovered boards varying in size from six-by-seven to 17-by-18 squares at sites scattered across the former Roman Empire. This raises the question of whether the game was played on all these boards or whether some boards were used for other games.

Browne was among the researchers involved in the Digital Ludeme Project – a five-year project that ran until 2023 – who used AI-simulated gameplay to investigate which board sizes make the most sense for proposed rules of the game. He worked with Walter Crist at Leiden University in the Netherlands and other colleagues to identify three games still played today – Kharebga, Seega and Tablut – with rulesets bearing a strong resemblance to Ludus Latrunculorum. They adapted the rules to accommodate the different-sized boards. The three rulesets were then played by opposing AI gamers.

These simulations showed that game sessions became mind-numbingly long as the board size increased, leading the researchers to conclude that the smaller boards were most suitable to the descriptions of Ludus Latrunculorum found in ancient Roman sources. "The larger boards, which are found on the outskirts of the Roman Empire in some of the forts in Spain, Egypt and Britain, are probably some other games that we don't know about," says Crist. Exactly which games is a mystery yet to be solved.

Looking forward, more than 200 computer scientists, archaeologists and historians have teamed up in a new European network called GameTable to develop even more sophisticated AI-powered digital tools for studying historical games. One goal is to create more human-like AI players. Another goal is to "create a unified database documenting ancient and traditional games, their rules and historical contexts, while highlighting cultural links across different regions and periods", says Piette, leader of the GameTable network.

Using this kind of family tree, the evolution and origins of games can be traced back over time. Through this, we might discover that many ancient games didn't die out, but developed into games still played today. Finkel, for example, thinks that the Royal Game of Ur was ultimately replaced by backgammon. "A 'good' board game... is unlikely to die," he says, "but will evolve into something more vital." ▮

Jeremy Hsu is game if you are

Survival of the wittiest

Could ancient two-word insults have spurred the evolution of complex language, wonders **Colin Barras**

WE WILL never know who spoke the first sentence or what they said, but we can have some fun speculating. Perhaps it came out of the mouth of a Stone Age man who hoped to defeat a rival and win the affections of a young woman. He might have sidled up to his love interest and, while furtively pointing at his competitor, whispered gently in her ear something that translates into English as "shit-head".

Ridiculous? Not if you are guided by the research of linguist Ljiljana Progovac. She points out that although Charles Darwin described language as "half art, half instinct", most people who study its evolution have neglected the creative element. Her research starts to redress that by homing in on the wordplay involved in compound phrases such as shit-head, skin-flint and lily-livered, many of which are written as single words today. These, she believes, are linguistic fossils that hint at a crucial stage in language evolution: the moment when humans realised that they could string two words together to create very short sentences.

What's more, after gathering examples of such phrases, Progovac noticed they have something surprising in common. "They are usually derogatory," she says. And there could be a good evolutionary reason for that too.

Language is central to the human experience, but studying its ancient roots is difficult because it leaves no archaeological traces – at least until the invention of writing. Nevertheless, judging by communication systems in other animals, we can assume that our ancestors started by making simple noises or gestures and, later, began to combine these in ever more complex structures.

The way words are combined to form phrases and sentences is called syntax. And many linguists classify the components of a sentence hierarchically from simple sounds and words to more complex phrases and clauses. But Progovac, who is at Wayne State University in Michigan, goes one step further: she believes the components at the bottom of the syntactical hierarchy preserve evidence of an earlier stage in the development of language. They are linguistic fossils.

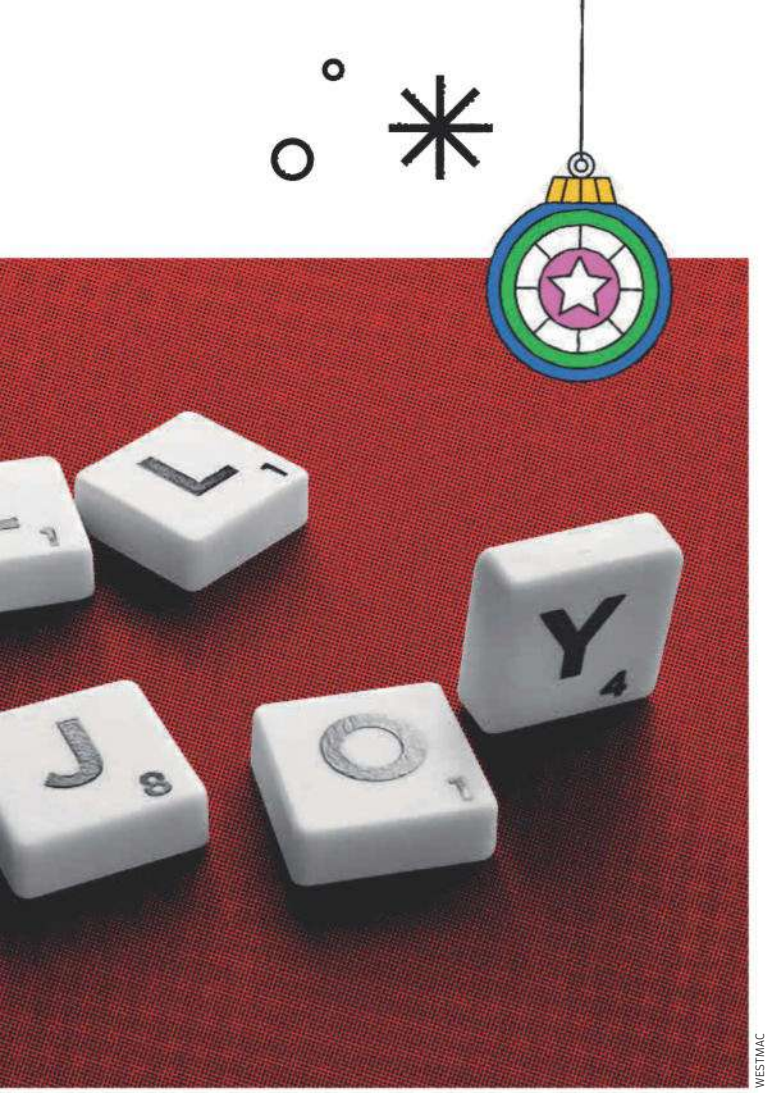
Take the sentence "Elena will grow wheat". It contains a short clause – grow wheat – that makes sense on its own. The remaining words expand this clause by telling us who is growing the wheat and anchoring the activity in time. For Progovac, this means our ancestors came up with phrases like "grow wheat" first and the expansions came later as language became more sophisticated. Analyse this syntactical hierarchy across modern languages, says Progovac, and you will find a curious class of two-word clauses right at its bottom. "They have very little structure," she says. "They are proxies of the earliest grammars."

Intriguingly, many of these phrases are combinations that have their origins in a noun and a verb, juxtaposed to produce a creative put-down: think kill-joy, busy-body, scatter-brain and arse-licker. And this is also the case in non-English languages. For example, Serbian versions include poj-kurić (sing-dick, meaning womaniser) and jebi-vetar (fuck-wind, meaning charlatan). Because of this, Progovac suspects that prehistoric humans first began combining words into short sentences at least partly to insult one another.

"Many of these 'linguistic fossils' are noun-verb phrases: kill-joy, busy-body, scatter-brain"

To appreciate why our ancestors might have felt this urge, it is necessary to consider the broader evolutionary context. Most anthropologists now agree that humans went through a process of self-domestication starting around 80,000 years ago – meaning there was selection for individuals who were less physically aggressive. This would have brought benefits. In particular, people who befriended rather than fought the strangers they encountered would then have had allies they could turn to for help during tough times. Hence, the idea is sometimes referred to as survival of the friendliest.

However, even as our ancestors became less aggressive, they continued to compete for social rank. Progovac suggests that creative and witty insults helped replace physical fighting as a weapon in this competition. "I think she has a point," says Vanessa Woods at Duke University in North Carolina, who recently co-authored a book on human self-domestication. "Language is used to form coalitions and gain status." Moreover, if the



WESTMAC

capacity for clever wordplay was controlled to some degree by an individual's genes, this desirable trait would have been subject to natural selection – meaning verbally creative individuals would have had more children and, overall, humanity's skill for language would increase. Progovac believes this was the case – and she calls it survival of the wittiest.

"It's a fun idea," says Gillian Forrester at the University of Sussex, UK. "But ideas like this are often very difficult to test because we don't have our ancient ancestors around to study."

Progovac accepts this. Nevertheless, she points to various lines of research that lend support to her thesis. For a start, non-human primates that have been taught to communicate using either symbols or sign language sometimes produce two-word phrases. Koko the gorilla, for instance, described a stale bun as a "cookie rock". The phrase has a certain wit about it, but it obviously wasn't invented to put down or impress other gorillas. Still, the fact that non-human primates can spontaneously invent such word combinations indicates that this ability wouldn't have been beyond hominins with far smaller brains than modern humans.

Another strand of evidence comes from psychology. One study suggests men use language more creatively in the presence of attractive women or male competitors. Another finds that women are receptive to humour initiated by men, but that men aren't as receptive to humour initiated by women. Such sex differences are compatible with the possibility that there has been sexual selection for wittiness during our species' evolution. It doesn't explain why wit is found in both men and women, but other studies might. For example, research shows that more eloquent speakers tend to have higher status, and hence a higher chance of passing on their genes.

Progovac has even found support for her idea in the brain. Working with a team of neuroscientists, she used functional MRI to explore how people responded to the two-word clauses and to grammatically more complex clauses expressing the same idea. The former prompted far less activation in brain regions – including Broca's area – that are associated with sophisticated syntactic processing. Progovac says this fits with the notion that two-word clauses serve as proxies of an early stage of language development, before the brain became specialised for decoding language. Others disagree.

But even if the original sentence consisted of a two-word phrase like spanking-head or cack-handed, it needn't have been spoken as a weapon of competition. Penny Spikins at the University of York, UK, points out that witty insults are often used to reinforce social bonds rather than to attack rivals. "A close friend can make a joke about your vulnerabilities," she says. In this context, Spikins thinks insults are a little like play-fighting: two friends can trust each other to "get the banter right" without causing offence. Demonstrating trust like this is important, she adds, given evidence that we are more caring towards people we trust.

So, Progovac has a way to go to convince sceptics. But it is early days. "All hypotheses need to start somewhere," says Woods. "The most important thing you want as a researcher is for people to engage with your idea." Just hope they don't describe it as hare-brained or bone-headed. ▮

Colin Barras is never a killjoy

Mouse metropolis

Why was a 1970s rodent city seen as a gloomy harbinger of humanity's future? Biologist **Lee Alan Dugatkin** investigates

IN JUNE 1972, the Royal Society of Medicine in London hosted a symposium called "Man in His Place". It featured an eclectic group of speakers, including Jacob Bronowski, whose acclaimed 13-part BBC television series, *The Ascent of Man*, would air the following year. But the first person to take the podium was John Bumpass Calhoun from the US National Institute of Mental Health outside Washington DC.

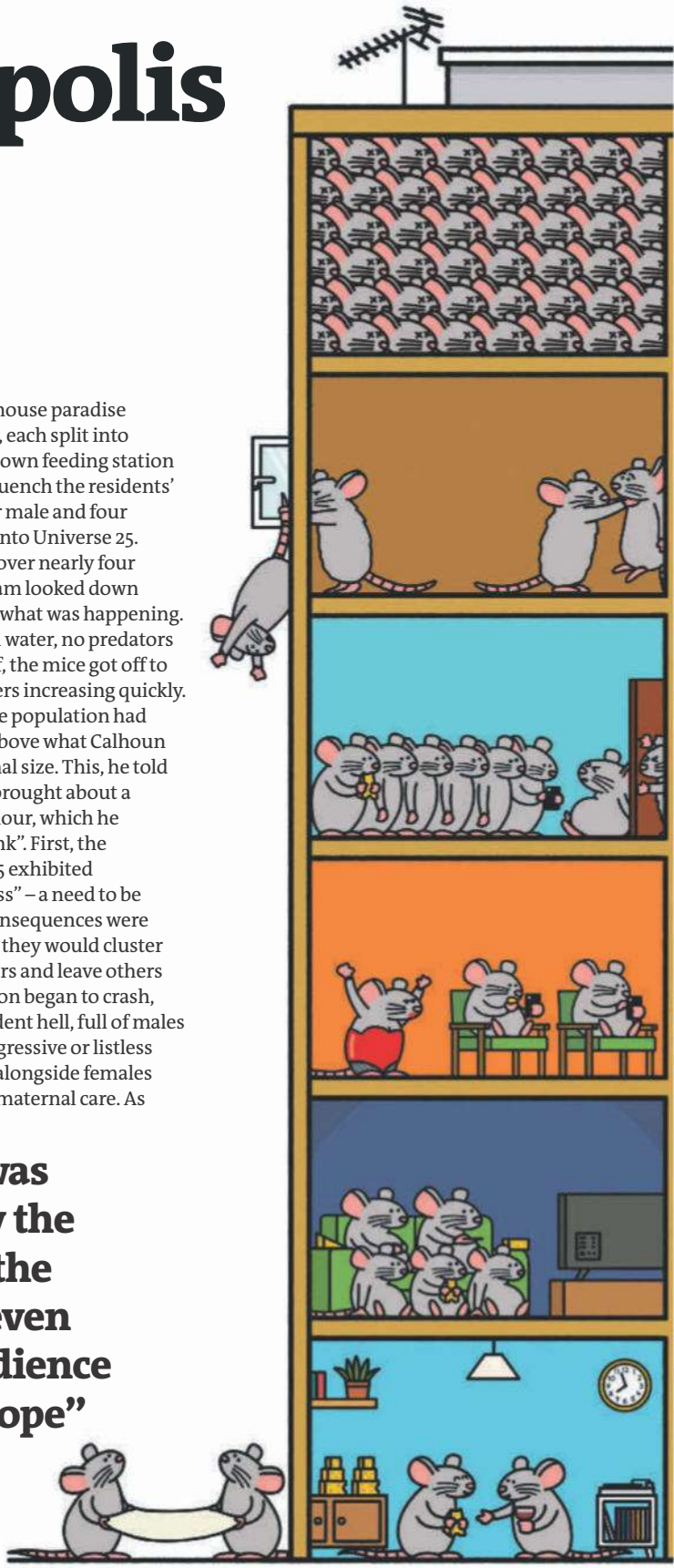
Even audience members familiar with Calhoun's work had no idea what was in store for them, and the title of his talk – "Death squared: The explosive growth and demise of a mouse population" – didn't give much away. "I shall largely speak of mice," he began, "but my thoughts are on man, on healing, on life and its evolution." He then went on to describe a long-term experiment he was running on population dynamics involving mice living in a "Utopian environment" that he dubbed Universe 25. Although his study subjects were rodents, Calhoun believed his metropolises had implications for humans: this was a cautionary tale of the chaos and social collapse in store for humanity in an overpopulated world.

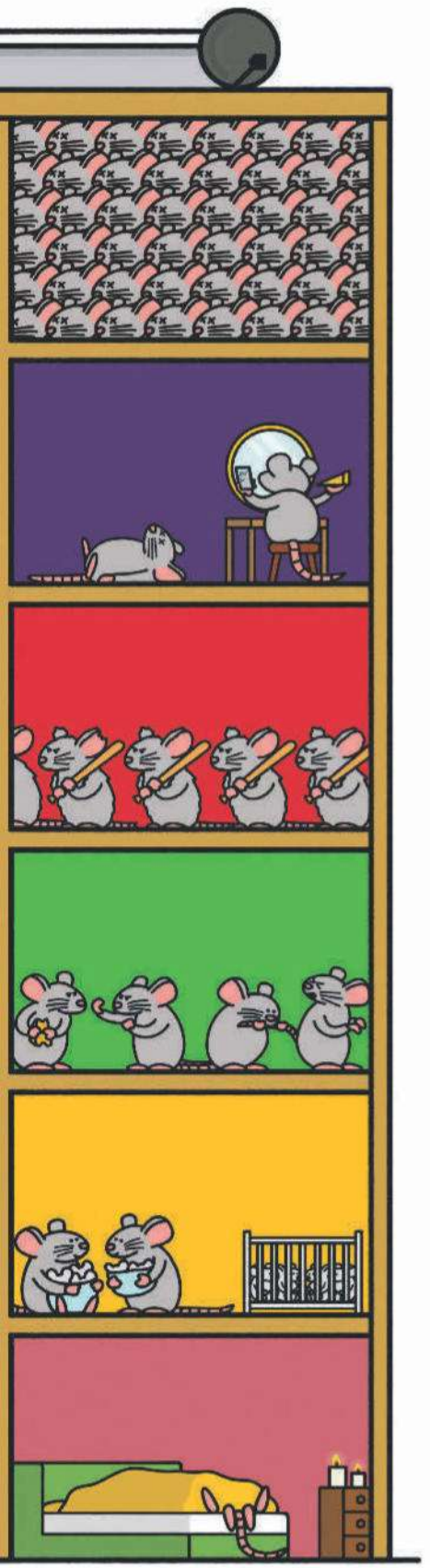
An ecologist-turned-psychologist-turned-futurist, Calhoun became a science rock star in the 1970s. His message struck a chord at a time when the human population was expanding rapidly and overcrowding was a hot political issue. As interest grew in his research, Calhoun was courted by the great and the good, from politicians and urban planners to prison reformists and writers. He even had an audience with the pope. Strange as it may seem, his rodent cities would influence many quarters of society for years to come.

Calhoun first came to public attention in 1962, following the publication of an article in *Scientific American* in which he described his study charting population growth and decay among rats living in an experimental barn not far from his labs. Both excited and alarmed by his findings, Calhoun subsequently established a series of rodent metropolises, including Universe 25, a mouse paradise consisting of 16 buildings, each split into 16 apartments, with their own feeding station and rooftop fountain to quench the residents' thirst. On 9 July 1968, four male and four female mice were placed into Universe 25. Then, for hours each day, over nearly four years, Calhoun and his team looked down from above and recorded what was happening.

With plentiful food and water, no predators and no disease to speak of, the mice got off to a flying start, their numbers increasing quickly. After about 18 months, the population had skyrocketed to 2200, far above what Calhoun calculated to be the optimal size. This, he told the audience in London, brought about a collapse in normal behaviour, which he dubbed a "behavioural sink". First, the inhabitants of Universe 25 exhibited "pathological togetherness" – a need to be near others, even if the consequences were negative. So, for example, they would cluster around a handful of feeders and leave others full. Then, as the population began to crash, life degenerated into a rodent hell, full of males that were either hyper-aggressive or listless and lacking sexual drive, alongside females that displayed almost no maternal care. As

"Calhoun was courted by the great and the good. He even had an audience with the pope"





STEVE NELSON

the crash progressed, growing numbers of mice spent most of their time grooming themselves and eating, while shunning all social interactions. Calhoun called these "the beautiful ones" and noted that they were capable of only the simplest behaviours compatible with physiological survival.

"Normal social organisation breaks down, it dies," he told attendees at the 1972 symposium. By that time, there were only 121 mice left in Universe 25 and the population was headed rapidly to extinction. This was a warning for humanity, he believed: if we didn't control our own population growth and reduce overcrowding, we too might destroy ourselves.

Calhoun's work on Universe 25 propelled him to international fame. The day after he gave his lecture in London, *The Daily Telegraph* ran two stories about it: "Mice point way to doom..." and "Sad elderly mice". CBS Morning News sent a camera crew to film Universe 25 and ran a long piece about population explosions and implosions on its morning and evening shows. Newsweek's Stewart Alsop also visited. "It's a lovely day – much too lovely to spend in an office," his article began. "In fact, it seemed a perfect day to visit Dr. John Calhoun's mousery." When the last survivor in Universe 25 died, *The Washington Post* even ran a front-page story titled "Ten boxes of dead mice could be us: Is modern mankind becoming a giant colony of mice?".

With Calhoun's star on the rise, politicians started to take notice. US senator Robert Packwood was quick off the mark. In April 1971, he stood in the Capital building and told his fellow senators that a "critical aspect of the population problem is being studied by Dr John Calhoun" and then pleaded for his colleagues to take the human population explosion seriously. A few years later, Calhoun wrote to President Nixon, warning that this was the greatest crisis faced by humanity in 50,000 years. Nixon, however, didn't respond – he was no doubt preoccupied with his own personal crisis, Watergate.

However, Calhoun's ideas were heeded elsewhere, with practical consequences. In 1971, he was consulted by the prison authorities in Washington DC and, in time, his work played a role in reforming dangerously overcrowded prisons. Likewise, city planners were considering the implications of his studies for urban development. In Philadelphia, for example, Calhoun's findings persuaded a committee charged with revising the building code not to reduce the minimum space per person in city dwellings.

Meanwhile, member of congress Barry Goldwater Jr wrote to Calhoun to say that

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John Calhoun in one of his experimental mouse "universes"

his findings "appear to coincide with certain theories now being evaluated by land-use planning consultants working with [my] staff" and requested an in-person meeting to discuss the "possible relationships between your findings and our investigations". Alas, it is unclear whether this meeting occurred.

Calhoun's ideas were soon making inroads into the popular psyche, too. They played a lead role in the 1969 documentary movie *Multiply and Subdue the Earth* and in Tom Wolfe's hard-hitting essay "Oh rotten Gotham! Sliding down into the behavioral sink". Following a visit to Calhoun's lab, Robert C. O'Brien was inspired – or so Calhoun believed – to write the wonderful children's story *Mrs Frisby and the Rats of NIMH*. In September 1973, Calhoun even met Pope Paul VI at the Special World Conference on Futures Research in Rome.

Calhoun died in 1995. Today, the human population sits at twice what it was when he extrapolated from his rodent experiments to issue his dire warnings. The social breakdown that he feared might happen if humanity didn't take action to curb overpopulation hasn't (for the most part) materialised.

But Calhoun did live to see one of his predictions come to fruition: he forecast a "conceptual revolution" that would give birth to a global "electronic prosthesis", a worldwide cybernetic brain. By the time he died, the internet had started to become a reality. ▮

Lee Alan Dugatkin's won't be sharing his cheese this Christmas. His book *Dr. Calhoun's Mousery* is out now

A glitch in time

Time travel isn't impossible, in principle – and physicists have never stopped exploring ways to make it happen, says **Miriam Frankel**

ADOBE STOCK

THE bartender says: "We don't serve time travellers in here." A time traveller walks into a bar.

OK, yes, I will almost certainly regret starting this article with such a hoary old joke. At some point, most of us have wished we could travel back in time to repair some misstep or faux pas. But it's impossible, right?

Well, not necessarily. Albert Einstein's general theory of relativity suggests that time travel may indeed be possible. We know that matter can bend space-time, and if you bend it enough, you may be able to create a time loop. Caveats abound, of course, and researchers are yet to announce a working time machine. But that hasn't put them off exploring the possibilities.

Here are five ways that time travel might just be feasible, from science fiction staples to surprising new ideas – as well as some pesky practical obstacles we would need to overcome.

1. Rig up a galactic ring of lasers

The main problem with time travel is that nothing can travel faster than the speed of light, which clocks in at 299,792,458 metres per second. This speed limit preserves causality, the idea that cause must always come before effect. Travelling faster than the speed of light would scramble that, thanks to a quirk of Einstein's special relativity and the fact that space and time are inextricably connected. If we could go faster than light, we would be travelling back in time. But we can't.

The next best thing, then, is to manipulate the fabric of space-time. In 2003, Ron Mallett at the University of Connecticut found that a rotating ring of lasers may be able to warp space-time so much that it curves in on itself, creating a time loop. This works because light can produce a gravitational pull just like matter can. "The rotating light would pull space-time along with it," says Ken Olum at Tufts University in Massachusetts, who wasn't involved in the research.

Sadly, though, it isn't just a case of stringing together a bunch of laser pointers – your laser ring would need to be of galactic proportions. Plus, even if that were possible, such a cosmic laser vortex would create a singularity, a point where space-time is so warped that the laws of physics break down, says Olum.

That would be a problem. "When you allow singularities, all hell breaks loose and anything is possible," says Toby Wiseman at Imperial College London. Physicists don't understand singularities, but what is clear is that we would be unlikely to survive an encounter with one.

2. Swing on a cosmic string

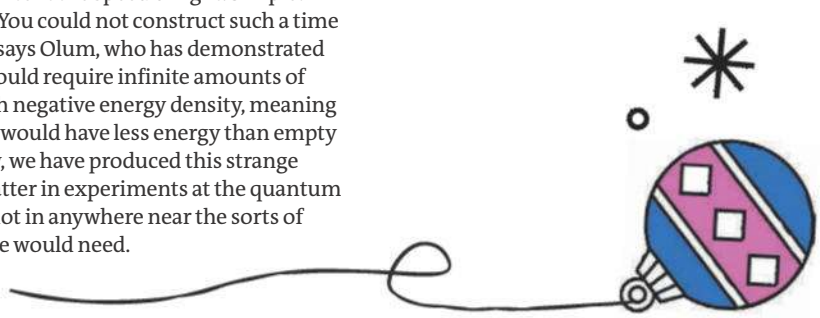
On to the next idea, then, which could at least be survivable, in theory. This one involves hypothetical filaments running through the fabric of space-time, called cosmic strings, and some seriously strange matter.

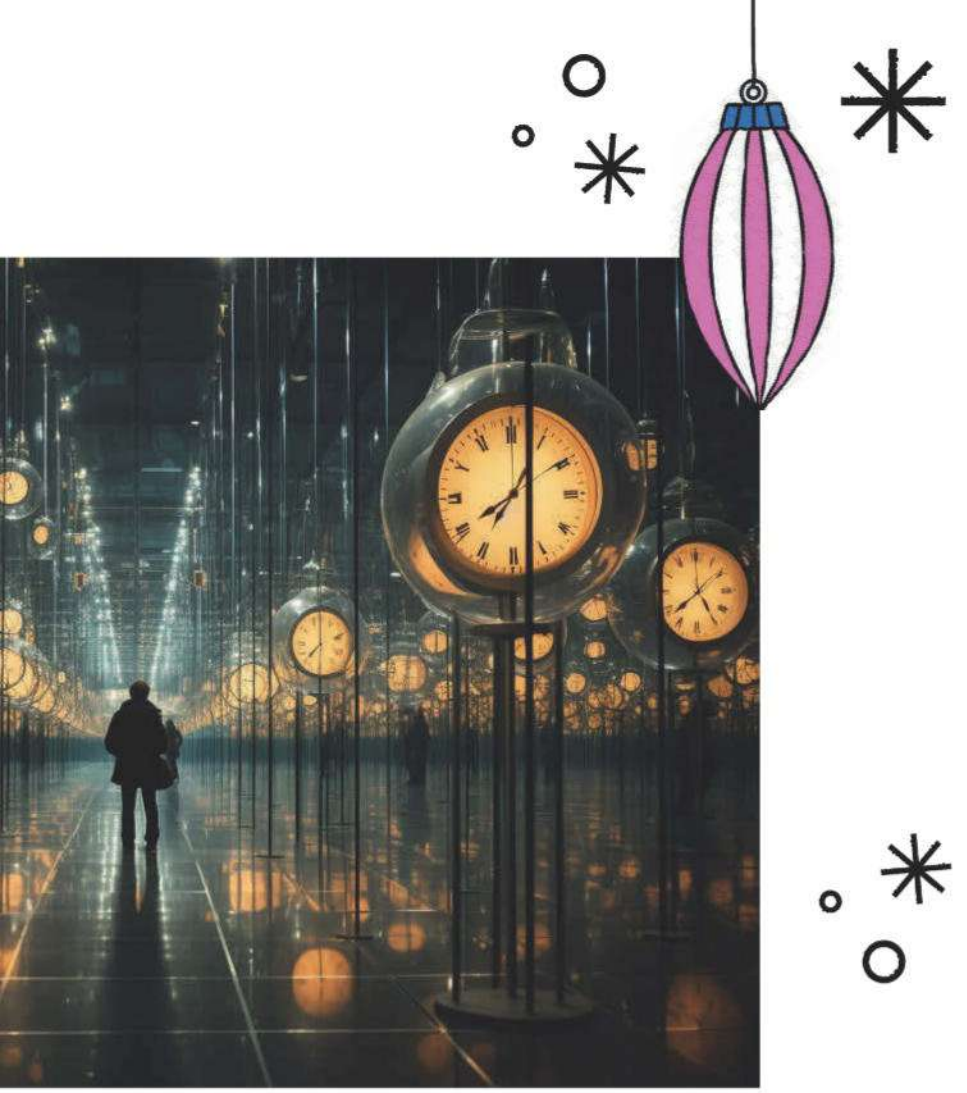
The idea is that cosmic strings could have been created moments after the big bang as the newborn universe changed phase – just like water does when it freezes – from higher to lower energy. If they exist, and we are yet to confirm that, they would essentially be long, thin strands of extremely high energy density left behind from the fiery first throes of the universe.

In 1991, J. Richard Gott at Princeton University calculated that two moving, infinitely long cosmic strings could produce a time loop, if they were oriented correctly. The time loop would arise as the strings crossed each other while moving in opposite directions. To go back in time, you would have to travel around them at 99.99 per cent the speed of light. Simple!

Or not. "You could not construct such a time machine," says Olum, who has demonstrated that this would require infinite amounts of matter with negative energy density, meaning the matter would have less energy than empty space. Now, we have produced this strange form of matter in experiments at the quantum scale, but not in anywhere near the sorts of volumes we would need.

"Such a cosmic laser vortex would create a singularity. That would be a problem"





"It creates only a very small amount," says Katy Clough at Queen Mary University of London. What's more, she says, it requires huge amounts of positive energy to maintain the effect, so creating a macroscopic amount may not be plausible, let alone an infinite supply.

3. Wangle a warp drive

So far, our putative time machines appear to be plagued by practical snags. Would that also be true of the most famous mode of time travel, the warp drives popularised by *Star Trek*, which would let us travel faster than light after all?

A warp drive is a hypothetical engine that creates its own personal bubble of space-time. They don't require any kind of traditional engine or propulsion, relying instead on compressing space-time itself. The engine would consist of a shell of matter that could somehow shrink the space-time ahead of it while expanding that behind, changing its location without technically moving.

Here's the thing: the cosmic speed limit only applies to objects moving through space-time, so a spacecraft within the safety of a warp drive bubble could reach speeds faster than light without breaking the laws of physics. Moreover, it wouldn't kill you – you wouldn't even feel it, says physicist Jared Fuchs, who studied warp drives while at the University of Alabama in Huntsville.

That would allow for time travel, in principle. Alas, as with the cosmic string time machine, a warp drive that could enable this faster-than-light travel would require huge amounts of matter with negative energy density.

4. Jump through a wormhole

Maybe this whole project would be easier if, instead of trying to build your own time machine, you used one lying around in the universe: a wormhole.

These hypothetical tunnels through space-time have two or more connecting mouths, usually black holes. If you could travel through the tunnel, you could theoretically end up in a distant place both in space and time.

The good news is that traversable wormholes "could already exist in our universe", says Wiseman. The most plausible way one might arise, without the need for negative energy, is between two tiny, charged black holes orbiting each other. Unfortunately, there's another snag: the tunnel would be subatomic, much too small for a human to enter, so it probably isn't the best mechanism for time travel. And even if we found a wormhole we could squeeze through, it is unclear whether we would survive the journey – the incredible acceleration and radiation may well be deadly.

That said, there could be a safer option out there: ring wormholes, which wouldn't be tunnels but rather flat portals made of negative energy. The negative energy would warp space-time to permit travel just like a regular wormhole, but there would be no lethal black holes involved. "If you went through one, you wouldn't experience anything in particular," says Andrei Zelnikov at the University of Alberta in Canada. "It would be like walking through a door."

5. Send a message to the past

If jumping into the inky blackness of a wormhole sounds too terrifying, there is an altogether safer option. Quantum mechanics may offer us a way to send a message back to the past, which is surely the next best thing to time travelling yourself.

The equations of quantum mechanics, which describes the world of atoms and subatomic partices, work equally well backwards as forwards. This makes it possible to interpret some quantum effects as involving signals sent back in time, though it is unclear whether that is what is actually going on.

Last year, researchers led by David Arvidsson-Shukur at the Hitachi Cambridge Laboratory in the UK showed that the experimentally proven process of quantum teleportation – sending a particle between two points in space – could just as well be interpreted as sending a particle between two points in time. They are now working on an experiment to test this by sending a real particle effectively back in time.

This process wouldn't work with anything as big as a person. "It seems technologically impossible because there's so many particles involved in a human to teleport," says Arvidsson-Shukur. But with the right set-up, you could imagine sending a series of particles back in time and encoding patterns in their properties. Think of it like sending quantum Morse code into the past – which isn't hugely glamorous, but probably our best bet for now. ▮

Miriam Frankel is travelling forward through time, minute by minute, just like the rest of us

Riddle me this

Leone Mercedes has 12 fabulously festive scientific conundrums for you

QUESTIONS

1. Uncle Johannes has outdone himself this year, serving up an eight-course Christmas feast (though some of the dishes are a little unusual). In order, the first seven courses are: mousse, vol-au-vents, eggnog, milkshake, jelly, soup and upside-down cake. What might the final course be?

2. This entity can be found travelling at near the speed of light under the Swiss-French border. Change one letter and you get the name of something it turns into. What are these two things?

3. What does this code, which might be delivered to you upon opening your front door, represent? (Hint: 262 usually appears in the middle.)
587 / 523 494 523 587 494 523 / 494 440 494 523 440 494 / 440 392 440 494 392 440 / 392 370 392 440 370 392 / 370 330 349 392 330 370 / 330 294

4. After the frontal lobe makes a call and the limbic system sends a signal, 15 facial muscles contract, including the zygomaticus major. The muscles between the ribs spasm, forcing air out of the lungs. Speech may become strained and reach a higher pitch than normal. Tears may emerge. But there is no reason to be alarmed. Why?

5. All three of the following describe different objects that share a name, and all might be seen during December – at least in the northern hemisphere. What is the name?
- A mixture including emulsified vitellus, crystalline sucrose, alcohol and acid
- A sphere of compacted crystalline dihydrogen monoxide
- A hemisphere of aerated sucrose and gelatine, encased in a layer of particles dispersed in a crystallised fat matrix, and coated in desiccated drupe shavings

6. What, logically, could come next in this sequence? Elementary particles in the standard model (pre-2012); horns on a trio of triceratops; nucleotide bases in RNA.

7. Although used as a metaphor for a rare event, this phenomenon has occurred on several occasions when the atmospheric conditions have been right. In fact, it is due to happen next on 31 May 2026. What is this it?

8. The following terms all have something in common. What is it?
· Uranium oxide powder
· The playful inspiration for a code name given to a mystery radio signal in 1967
· Random motion of microscopic particles suspended in a fluid
· The change in wavelength of an approaching celestial object

9. See if you can get this one in a snap. These significant figures describe spectacular moments in history:
1827: 0 km; 1946: 105 km;
1968: ~400,000 km;
1990: ~6,000,000,000 km
The same thing happened each time. What is it, and what do the numbers represent?

10. Fill in the blank:
With this, you lend an ear / With this, there is nothing to hear / With this, your tree can raise a grin / Tellurium, lithium, ...

11. A land snail native to Fiji takes the first part of its name (the genus) from an area in which it resides: the Mba, or Ba, district. Malacologist Alan Solem gave in to an "irresistible impulse" when giving it its second (species) name. What is the land snail's full name?

12. All together now: what do you get if you combine the total number of Platonic solids, an element used extensively in communication and decoration, and faraway structures shepherded by Prometheus and Pan?

KYLE ELLINGTON

The only puzzle Leone Mercedes finds tricky is whether to have yule log or Christmas pudding

ANSWERS

1. The courses share their initials with the planets of the solar system, in order, moving out from the sun. So any dish beginning with "n" would fit the bill – anyone for a naan?

2. Proton and photon. The Large Hadron Collider at CERN smashes together protons and the ATLAS experiment examines the debris, which includes photons.

3. Take a deep breath... This is each of the 33 notes of "Gloria", as sung in *Ding Dong Merrily on High*, expressed in hertz according to the scientific pitch notation system, where 262 Hz is middle C. (NB: These have been rounded to the nearest whole number.) You might get a rousing rendition after opening the door to carol singers.

4. Ho ho ho, sounds like someone's just told a joke. This is what is happening inside your body when you hear a good rib-tickler and start to laugh.

5. Each of these describes a different type of "snowball": the first is the advocaat-based cocktail, the second is the kind that you might hurl on a snowy day and the third is the marshmallowy, chocolatey, coconutty confection.

6. There were 16 elementary particles in the standard model before the discovery of the Higgs boson, three tricreatops would have a total of nine horns and there are four nucleotide bases in RNA – cytosine, guanine, adenine and uracil. These are square numbers in descending order, so next in the sequence would be something there is only one of, such as protons in a hydrogen atom.

7. A blue moon. The traditional definition of a blue moon is the third full moon in an astronomical season that has four, which happens about every two or three years. The moon has also appeared blue in colour after volcanic eruptions and forest fires.

8. They all include a colour. In order: yellowcake; little green men (abbreviated to LGM by pulsar discoverer Jocelyn Bell Burnell in the 1967 code name); Brownian motion; blueshift.

9. These numbers represent when famous photographs were taken of Earth and from what distance. We have, in order: the oldest surviving photograph taken by a camera obscura (so strictly, a picture of just a bit of Earth); the first taken from space, by a 35-millimetre film camera on a V-2 rocket; the *Earthrise* shot snapped from the moon's orbit in Apollo 8; and the *Pale Blue Dot* picture taken by Voyager 1, from far beyond the orbit of Neptune.

10. Tin. The first three lines describe words that are anagrams of each other: listen, silent and tinsel. The chemical symbols for the elements in the final line, when pushed together, form yet another anagram of the previous three words. So we have Te for tellurium, Li for lithium and Sn for tin.

11. If you said "Ba humbug", that's close enough. This particular snail is named *Ba humbugi*.

12. Five gold rings. There are five Platonic solids (tetrahedron, cube, octahedron, dodecahedron and icosahedron); gold is used in communication (as a key component in computers and mobile devices) and as decoration (in jewellery); and the shepherd moons Prometheus and Pan maintain the rings of Saturn by their gravitational influence.

What a coincidence!

From lightning striking twice to identical lottery draws, seemingly impossible events happen all the time. Mathematician **Sarah Hart** reveals why

I HAD a strange experience in a cafe recently. When paying for coffee, I asked to use the toilet. After I tapped my PIN into the card reader, the barista handed me a slip of paper that was blank apart from a single number – the same one I had just tapped into the keypad! It turned out that this was also the entry code for the bathroom door.

Was this evidence of a shadowy plot by the agents of Big Caffeine? No, it was just a fluke, but the event got me thinking about coincidences more generally. Occasionally, we are faced with events that seem so improbable we can't help but feel the universe is sending us a message. As a mathematician, I know that coincidences are often far more likely to occur than we think – and this fact can have serious consequences everywhere from the science lab to lottery kiosks and the law courts.

My coffee shop experience is a good place to start because we can calculate the exact probability of it happening by chance. There are 10,000 possible four-digit numbers, meaning a 1 in 10,000 probability that the door code matches my PIN. Unlikely, yes, but let us put it in context. The cafe was in York, UK – a popular tourist destination with 8.9 million visitors annually. If each visitor has one bank card, we would expect around 890 cards each year to have the same PIN as that cafe's bathroom door code. I don't feel so special now.

The cafe coincidence illustrates an important fact: even very improbable events are likely to occur if given enough opportunity. We can express this mathematically as follows. With k opportunities for an event to occur, at each of which there is a one in n chance of it actually happening, then (assuming the events are independent) the probability it occurs at least once is: $1-(1-\frac{1}{n})^k$.

Don't let the algebra put you off: the take-home message is that the chance of a coincidence rises quickly as the number of opportunities increases. From this formula, we can derive the following fact: the probability of a "one-in-n" event happening at least once exceeds 50 per cent whenever there are more than $0.7n$ independent opportunities for it to occur – a phenomenon I call the 0.7 rule.

TZAHIV/GETTY IMAGES

JONATHAN HIGBEE

DENIS CHERIM

The human brain can easily attribute meaning to random occurrences

Let us consider a couple of examples. Suppose everyone in Birmingham has a one-in-a-million chance each night of dreaming tomorrow's news. As the population is over 700,000, it is more likely than not that each morning someone in Birmingham becomes convinced they are psychic.

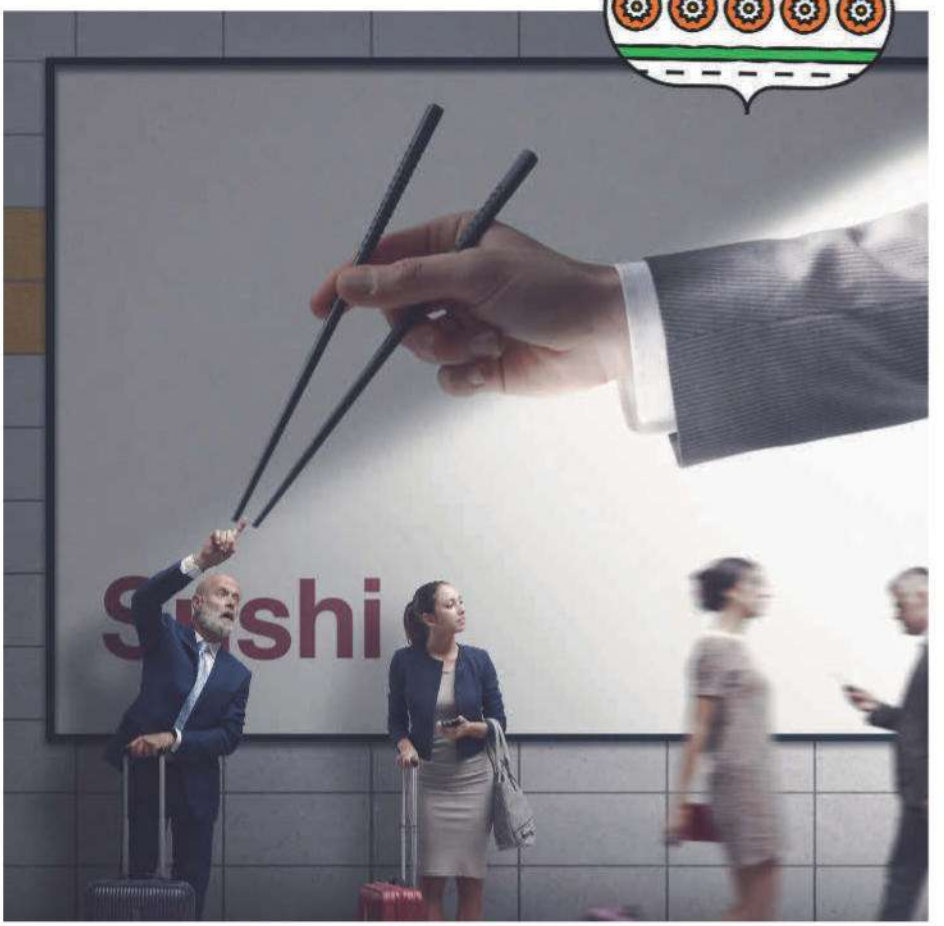
Every day, there are many ways a freak coincidence could happen to you. Say you have one opportunity per hour to experience such an event, and the median life expectancy of 706,000 hours, there is a better than even chance you will experience a one-in-a-million coincidence at least once.

Such analyses can help explain some of history's most breathtaking coincidences, such as the curious case of the Bulgarian national lottery. In September 2009, the same numbers – 4, 15, 23, 24, 35 and 42 – came out in two consecutive draws.

It sounds like a fix, but the statistician David Hand calculated that the game would only have to run for 43 years before it becomes more likely than not for the same numbers to be drawn at least twice. (The lottery had, by this point, been running for 52 years.)

Each lottery ticket has an equal chance of winning, but people aren't lottery tickets, and so the probability of experiencing a rare event can vary from individual to individual. Roy Sullivan, a Virginia park ranger, was struck by lightning seven times between 1942 and 1977. That is certainly unlucky, but he had more chance than most. There is more lightning in warmer, wetter parts of the US, and people with an outdoor job are more exposed than those who are protected indoors. This latter risk factor partly explains why men account for 84 per cent of deaths by lightning strike.

Occasionally, odds can appear more impressive than they truly are. Famous "psychic" Jeane Dixon's prediction that



LUCIANO DE POLO STOKKETE/ALAMY

John F. Kennedy would win the 1960 presidential election and die in office looks unsettlingly prescient, until I tell you that she had also forecast a Nixon victory in 1960 and the start of World War III in 1958. Never mind, Jeane. As Niels Bohr famously said, prediction is very hard, especially of the future.

Sometimes, of course, there really is something more going on. If Edward Jenner had dismissed the curious fact that milkmaids were unusually immune to smallpox, he might never have uncovered the protection provided by a previous cowpox infection, which led to the world's first successful vaccines.

Distinguishing between coincidences and deeper causes is central to the scientific method and can also resolve accusations of plagiarism. Ed Sheeran's chart-topper *Shape of You*, for instance, was the subject of a 2022 lawsuit claiming that a sequence of four notes was lifted from Sami Chokri's 2015 song *Oh Why?*

"Coincidence is bound to happen if 60,000 songs are being released every day on Spotify," Sheeran told his fans after winning the lawsuit. "That's 22 million songs a year and there's only 12 notes available."

He is right – with 12 notes in the Western octave, the number of possible four-note phrases is a mere 20,736. It is a mathematical certainty that many of those 22 million songs will contain uncannily similar passages.

In academia, distinguishing coincidental resemblance from plagiarism or AI assistance in student essays is a growing challenge. One plagiarism detection tool called Turnitin has an estimated false positive rate of 1 per cent for identifying documents with more than 20 per cent AI content. But if you are in that 1 per cent, how do you prove you haven't cheated? One University of California, Davis, student, Louise Stivers, was only able to convince the university of her innocence by providing time-stamped drafts of her work.

"Roy Sullivan was struck by lightning seven times"

Small world

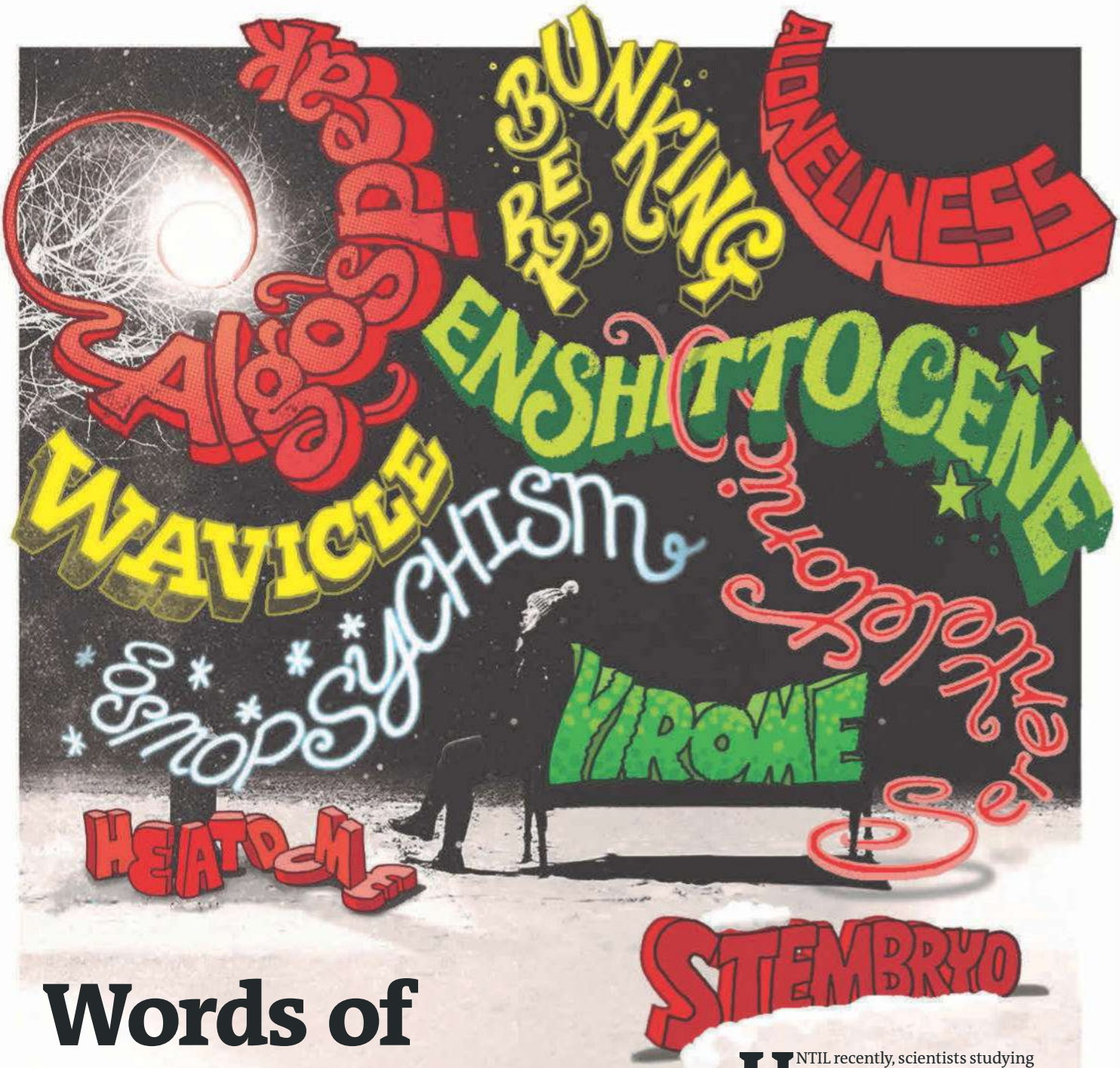
At this time of year, we often find ourselves chatting to strangers at parties, looking for things in common. Happily, such connections almost certainly exist. It has been estimated that we each know 1000 people (acquaintances, colleagues, neighbours: I will just say "friends" for short). If these connections are randomly distributed, it turns out there is a better than 99 per cent chance that you and I either have a mutual friend or a friend of yours knows a friend of mine.

In real life, social networks are far from randomly distributed: you are more likely to know someone from your own city than someone from elsewhere, for instance. Surprisingly, however, this doesn't have much impact on these effects.

Mathematicians Steven Strogatz and Duncan Watts discovered that the presence of a few highly connected individuals can lead the network's overall distribution to approximate that of a random one. This means that, even if people only have 100 friends on average, any two people in the world are probably linked by a chain of fewer than five mutual friends.

The cliché of dinner party small talk turns out to be true: it really is a small world. Thanks to the laws of mathematics, coincidences abound. Events that seem to be a matter of fate are often little more than a numbers game. ∎

Sarah Hart loves a mince π. She is the author of *Once Upon a Prime: The wondrous connections between mathematics and literature*



ANDY SMITH

Words of the year

From algospeak to viromes, this year has seen an eclectic mix of words elbowing their way from tech firms and scientific journals into our everyday vocabulary. *New Scientist* spells them out

UNTIL recently, scientists studying the earliest moments of human development relied on embryos donated by people undergoing IVF, which in most countries – including the UK and US – must be destroyed after 14 days. In 2023, however, a team at the University of Cambridge created the first complete stem-cell based human embryo model.

Stembryos, as they are known, can be studied for longer – and they are expected to produce fresh insights into developmental

conditions and the causes of early miscarriages, as well as improve IVF success rates. But consideration of the ethical questions inherent to this work hasn't kept pace. Which is why, in July, the UK published its first guidelines on the generation and use of stembryos in research, including the proposal that a committee be created to oversee all stembryo studies.

VIROME

We are, all of us, riddled with viruses – and thank goodness for that. The average human is host to as many as 380 trillion of them, collectively known as the virome. But while some viruses make us unwell, scientists now understand that the legions of viruses living inside us have a broader and more profound influence on our general health.

Viruses make up a critical part of something we are more familiar with: the microbiome, that vast population of microorganisms that make camp both inside and on us. Scientists believe the virome regulates the composition of the microbiome and also plays a critical role in our immune system. It is hoped that a better understanding of this inner ecosystem could ultimately help us treat obesity and anxiety.

ALONELINESS

Introverts and parents of young children will understand this one in their very cells. Aloneliness refers to the negative feelings that arise when you don't spend enough time alone, a kind of conceptual foil to loneliness. The idea, coined in 2019 by Robert Coplan, a psychologist at Carleton University in Canada, acknowledges that though loneliness can harm our health, time in our own company isn't always a bad thing.

In fact, there is sanctuary in solitude. Research published in the past few years suggests aloneliness correlates with stress, depression and aggression, so finding time to read, exercise or just sit in a dark room by yourself can actually be restorative and necessary. Tell the kids it's doctor's orders.

HEAT DOME

If recent intense heatwaves made you feel like you were trapped in a pressure cooker, well, that isn't far from the truth. Record temperatures in southern Europe and persistent heatwaves in the US this year have been driven, in part, by a weather effect known as a heat dome.

This phenomenon forms when an area of high pressure in the atmosphere hovers over a region for days or weeks at a time, trapping warm air inside, like a lid on a pot, and keeping cool air and new weather fronts out. Some researchers have warned that human-caused climate change is increasing the duration and frequency of heat domes.

PREBUNKING

What if there were a way of debunking fake news before it goes viral? That is the idea behind prebunking, conceived as a kind of vaccine against the virus of misinformation to which we are all increasingly exposed. The concept, developed by researchers at the University of Cambridge, Google subsidiary Jigsaw and the BBC, involves circulating videos that encourage critical thinking and teach people about techniques used in deliberately misleading content.

It seems to work, too. In 2023, Google trialled targeted videos across social media that aimed at pre-empting misinformation about Ukrainian refugees. It found that people who had watched prebunking videos were significantly better at identifying misinformation. With fears of AI-generated misinformation heightened throughout the past year due to a slew of high-profile elections, a number of prebunking projects focused on protecting electoral integrity.

ALGOSPEAK

Do you know what "seggs" means? How about "unalive" or "le dollar bean"? If so, congratulations, possibly, for you must be fluent in algospeak, a native tongue of the chronically online.

On social media platforms, these terms are a form of shorthand or euphemism that users believe will help bypass algorithm filters that flag and deprioritise some phrases. "Seggs" means sex. "Unalive" can refer to death, killing or suicide. And "le dollar bean" means lesbian, this one an example of social platforms' text-to-speech technology pronunciation of "le$bian". But you knew that, right?

WAVICLE

The word "particle" gives the impression that everything from electrons to photons behaves, ahem, in a particular way. Alas, that isn't quite true. We think of particles as something like a speck of dust, albeit infinitesimally small. But we have known for a century that a particle is also a tiny wave, vibrating constantly.

Hence the return of "wavicle", a word first used in the 1920s to capture the idea of an entity that simultaneously has the properties of a particle and a wave. The physicist Matt Strassler is among those promoting the use of wavicle to help all of us better understand the true nature of particle physics. Wait, we might need to workshop a replacement for that term, too.

ENSHITTOCENE

"We're all living through the Enshittocene, a great enshittening, in which the services that matter to us, that we rely on, are turning into giant piles of shit." So says the writer Cory Doctorow, who coined the word "enshittification" to describe the way digital platforms degrade over time.

He proposes a four-step process: first, the service creates something good and useful to its users. Then, it abuses those users to attract more business customers like advertisers. Next, it abuses those business customers to retain value for itself or its shareholders. And finally, it dies.

COSMOPSYCHISM

Is the universe conscious? At first blush, it sounds like drug-addled whimsy. But in 2020, physicist Franco Vazza and neuroscientist Alberto Feletti published a paper arguing that, in fact, the structure of the universe isn't dissimilar to that of the human brain.

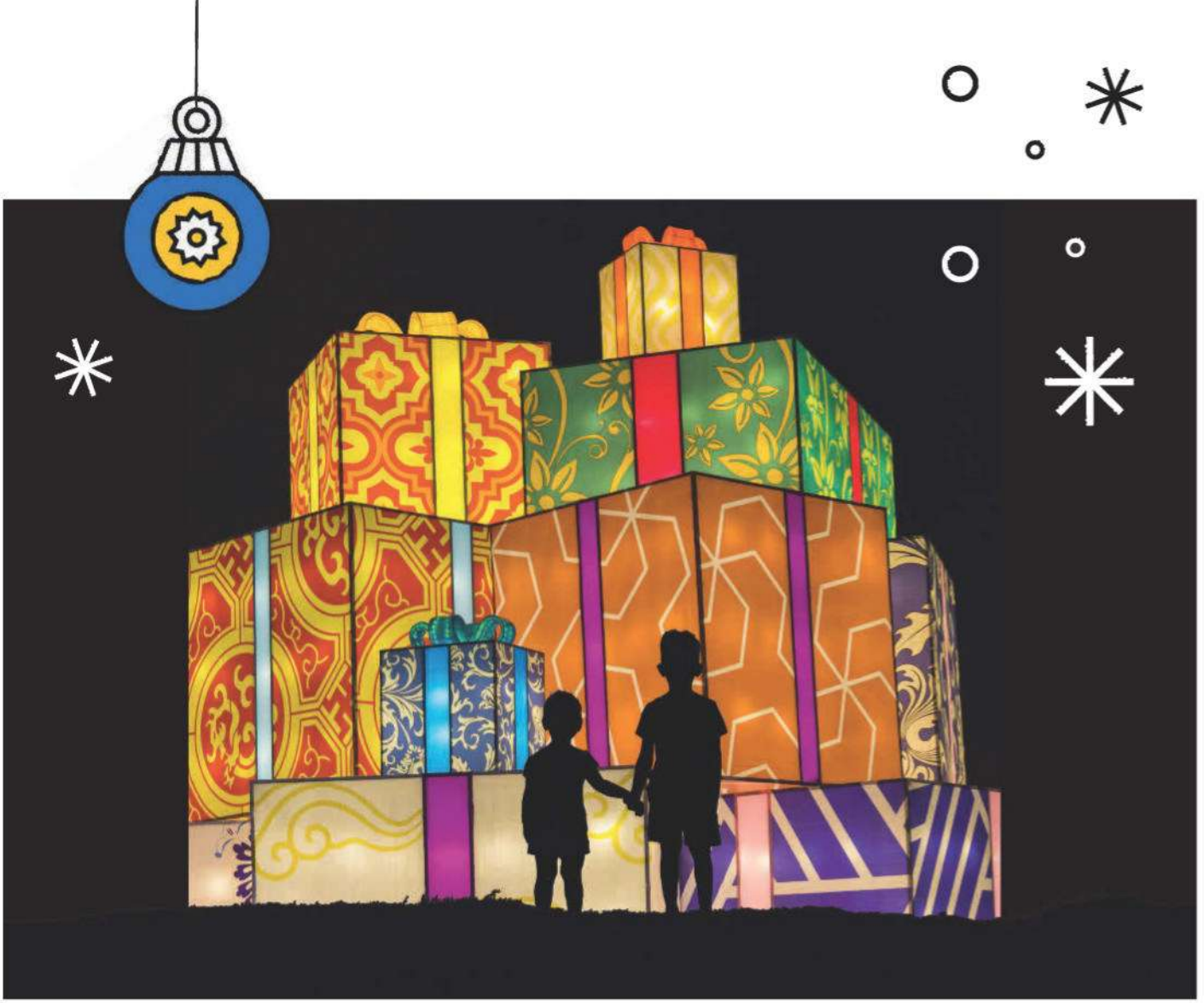
Matter and galaxies cluster together like neurons do, and they are connected by cosmic filaments that could be mistaken for the axons that transfer electrical signals through our brains. Since the origin of consciousness and the structure of the universe are two of the biggest questions in science, the similarities between brain and cosmos offer a tantalising suggestion: maybe they developed according to the same organising principles.

SERENTELETONIC

The next time you are munching on your breakfast cereal, stop and consider how unlikely it is that you came to be, right here, right now. How much cosmic and genetic probability had to play out to bring you here? How many chance encounters? How many sliding doors moments stretching right back to the dawn of time?

If you are now basking in the metaphysical wonder of this delicious thought experiment, you are feeling serenteletonic. The word was coined by writers Richard Fisher, Alexandra Balwit and Thomas Moynihan, in collaboration with the Bureau of Linguistical Reality, an art project for new vocabulary. It is an amalgam of serendipity, serene, tele – meaning at a distance – and tonic. The meaning, according to those who coined it, is "a feeling of awe when we recognise our position within long-term time". ▮

Ian Taylor is never lost for words



CAROLYN JENKINS/ALAMY

Toy story

Is there a perfect children's toy? Research shows that some of them really do help – or hinder – brain development, finds **Helen Thomson**

"LOYD," he tells me. "His name is Lloyd." Naturally. Why would a green Lego Ninjago be called anything else? The plastic figurine has shot to top spot on my son Sam's Christmas list.

Anyone who knows a young child will sympathise. They crave the Barbie Colour Reveal Deluxe Styling Head that promises instant-but-fleeting joy, whereas we want to buy the woodland activity kit that will surely nurture the body and soul.

If you find yourself despairing at such choices, help is at hand. Thanks to a growing understanding of the cognitive benefits of certain toys, we now have a better idea about the relative merits of different ones. This Christmas, I decided to use the research to help me identify the perfect toy – or at least get as close as I could.

Digging into this world, I soon discovered that some toys really are better than others for young brains, found that computer games aren't as evil as you might think and uncovered the secret to buying a toy that won't languish at the back of a cupboard.

You may think that toys are a relatively modern invention, but they have been part of our lives for millennia. Analyses of rock fragments in Western Cape, South Africa, dating back 60,000 to 80,000 years, suggest that children may have tinkered with blunt, functionally useless copies of adult stone tools. These ancient playthings are thought to have been key to the development of cognitive skills, such as our ability to envision alternative scenarios and to conjure new ideas that led to innovations such as the wheel and weaving.

Toys today can be just as cognitively nourishing, says child development researcher Jacqueline Harding at Middlesex University London. "The types of toys children play with can have a profound and lasting effect on the brain," she says, but some are better at achieving this than others.

Consider a Thomson family favourite: puzzles. Susan Levine at the University of

Chicago, Illinois, and her colleagues, found that children of between 2 and 4 years of age who play with puzzles, blocks and engineering toys have better spatial skills than those who don't. Spatial skills help our understanding of maths and science and have been shown to predict a child's academic success in these disciplines.

"When we're searching for the perfect toy, we really have to ask 'the perfect toy for what?'" says Salim Hashmi at King's College London. "Different toys are good for promoting different outcomes. Dolls are particularly good for promoting social skills, construction toys are good for spatial reasoning, balls are good for increasing exercise."

Nevertheless, particular attention has been given to toys that help develop executive function – a type of thinking that enables us to plan, focus our attention and juggle multiple tasks. It is associated with better academic performance, helps us regulate our emotional response in an argument and is vital for boosting the chance of achieving our goals. It is also a trait that develops rapidly from the ages of 2 to 7. Several studies have shown that it is possible to improve executive function in children by getting them to engage in 10 minutes of pretend play each day. So that is a tick for things like dolls, train sets, a doctor's kit – anything that stimulates the imagination.

What about the toys to avoid? "Anything that is plastic and rigid you'll find at the bottom of a drawer because it doesn't allow personalised play," says Harding. "Any toy that erodes the capacity for creative thinking is on my no-go list." In academia, these toys are called convergent – they have a single solution or limited number of ways to be used in play. Divergent, or open-ended toys, like Lego or magnetic tiles, can be played with in multiple ways. Several studies show that children who use divergent toys are generally better at problem-solving tasks compared with children who have convergent toys.

This is ringing bells. I recently bought my kids one of those steady-hand games where you steer a hoop at the end of a handle around a wire, which buzzes if the hoop touches it. They were delighted on the day, but it hasn't been used since. A convergent toy with a single purpose doesn't appeal for long.

Surprisingly, the best kind of toy might not even be a toy at all. There is growing enthusiasm for "loose parts play" (LPP), Hashmi tells me. LPP is any interactive material that isn't initially intended for play, but that, with a little imagination, can be manipulated in many ways – a cardboard box, a jar of shells or a pack of paper clips, say. LPP has many developmental benefits – particularly for older children – including promoting self-esteem, encouraging social interactions and fostering internal dialogues. "[That] is a really important message to get across," says Hashmi. "Not just for people who can't afford the latest toy, but also for sustainability."

PLAINPICTURE/HOLGER SALACH

Open-ended toys can improve problem-solving abilities

On that note, it is also worth knowing that less may be more when it comes to toys. When toddlers were given between four and 16 toys to play with, those who had fewer to choose from engaged with each toy for longer and played with it more creatively.

But let's face it, telling my kids that they are going to have fewer toys for Christmas, and that their presents may include paper clips, would not go down well. It is all very well knowing which toys are best for their cognitive chops, but what children desire doesn't necessarily match what is good for them.

For instance, Sam loves dinosaurs and trucks. I worry he is too obsessed with "boy toys". This preference for gendered toys is in part influenced by our genetics, says Jac Davis at the University of Cambridge, but mostly it is cultural. Children in villages with no access to modern technology, for instance, show no preference for pink or blue toys, unlike kids elsewhere. However, it is OK for children to have this preference, says Davis: it shows they can interpret the world around them and decide where they fit – but parents should vary the toys their children have access to so they have the chance to develop a variety of skills.

"Surprisingly, the best kind of toy might not even be a toy at all"

Fine, but what about Sam's growing preference for digital toys? To me, the perfect toy instinctively feels like it should be physical, not the latest PlayStation 5 console offering. Is there any cognitive value in a 4-year-old being able to complete a PS5 game? Just asking for a friend.

To find out, Hashmi and his colleagues analysed the brain activity of 4 to 8-year-olds while they played with dolls with an adult or on their own. The team compared this with when the children played open-ended games on a tablet. The research focused on activity in brain regions related to empathy, perspective taking and executive function. "When they played with dolls alone, it activated these brain regions more than playing the tablet alone. They also talked more – that was quite a stark comparison," says Hashmi, suggesting that it may be better for kids to play with physical toys rather than digital ones when alone.

Interestingly though, when an adult played the computer game with the child, their brain activity matched that of playing with dolls alone. "The presence of the adult was more important than the toy itself," says Hashmi. Other studies back this up: when preschoolers play with adults, they boost the grey matter in their brain, which is associated with increased cognitive development in children up to 8. Meanwhile, most data that shows toys boosting cognitive skills comes from studies in which children are playing with adults, rather than alone. The idea that this is optimal is also consistent with studies showing that youngsters learn best in the context of "serve-and-return" conversations, where a child performs an action and there is an adult around to respond appropriately.

It is a nice ending to my search. "Perhaps the ultimate secret to choosing the perfect toy has nothing to do with the toy itself, but which one you like the most," says Hashmi. "It's the one you'll play with." ▮

Helen Thomson has given Santa strict instructions this year

Let it snow

How hard could it be to make the world's largest snowflake? **Madeleine Cuff** gives it a go

IN LONDON, where I live, you can forget about a white Christmas. The best I can hope for is a pitiful flurry of flakes. So, this year, I am on a mission to create my own snow. And not just any snow: for maximum festive impact, I want to make the world's largest snowflake.

It will be a challenge. The Guinness world record stands at 38 centimetres across and 20 centimetres thick. This whopper was recorded in Montana in January 1887, when ranch owner Matt Coleman reported seeing snowflakes "larger than milk pans" during a severe storm. Admittedly, some experts are sceptical. "If this was falling from the sky, they would probably need to be wearing crash helmets," says glaciologist Douglas Mair at the University of Liverpool, UK. Nevertheless, Guinness World Records insists that contemporary sources support the record.

But hold on! There's an addendum: the largest snow crystal measured 10 millimetres. "A snow crystal is a single crystal of ice," says Ken Libbrecht, who photographed the record-breaker in Ontario, Canada, in December 2003. The textbook image of a Christmas snowflake is actually a perfect snow crystal, he explains, whereas a snowflake is several crystals joined together. So perhaps I could break a record by making the world's largest snow crystal instead – how hard can that be? "You'll be able to grow some ice crystals from water vapour," says Libbrecht, who makes "designer" snow crystals in his lab at the California Institute of Technology. "But if you want to make it look like a snow crystal – I mean an actual symmetrical snow crystal – that's a tall order." Clearly, I will need some help.

My first stop is the Manchester Ice Cloud Chamber at the University of Manchester, UK. This 10-metre-tall, climate-controlled tube was designed to "build" ice clouds like those found high in the atmosphere, to improve the accuracy of weather forecasts. Atmospheric scientist Paul Connolly has used it to create snow crystals from scratch, so I am here to find out how that is done.

You start with a supercooled cloud of water vapour, he says. From there, you have two options. If the temperature is above about -38°C (-36°F), an ice crystal will form around a "nucleating particle", such as pollen or soot. If the temperature is lower than that, "homogeneous nucleation" occurs, with some of the water vapour spontaneously freezing to create the nuclei upon which crystals can form. Either way, under the right conditions, your crystal will begin to grow, drawing in surrounding water molecules from the air. And using the ice cloud chamber has advantages over nature. "We don't have to wait for the ice crystals to fall kilometres through an atmosphere," says Connolly. "We can speed up this process and do it within 10 metres." Unfortunately, however, the largest snow crystals he and his colleagues have created measure just 1 millimetre. Perhaps a bigger chamber would help.

Just down the road is Energy House 2.0, a climate-controlled warehouse run by the University of Salford that is designed to test new construction techniques. "There's nowhere else like it in the world," says technical lead Richard Fitton. Energy House 2.0 can produce an incredible diversity of temperatures and humidities – including extreme cold – making it the perfect place to try to grow my giant snow crystal.

I have assembled a crack team of experts to help. Alongside Connolly and Fitton, we have Fitton's colleague Grant Henshaw, Gordon McFiggans, an atmospheric scientist at the University of Manchester, and Mair. Energy House 2.0 has been set to a bone-chilling -18°C (-0.4°F), and there is a snow cannon all ready to go. Stage one, we agree, will be to see if we can encourage the cannon's ready-made snow crystals to grow bigger. The plan is to fire it twice: low first, and then higher. We are hoping this will provide a lingering cloud of supercooled water vapour for crystals generated at the top of the chamber to fall through. "In the atmosphere, the way we get the largest snowflakes is if small snow crystals can grow in a process known as vapour deposition," says Connolly. "That means water vapour condenses onto the ice crystals."

TIM ALEXANDER

Giant snowflakes
Watch Madeleine Cuff attempt to make the largest snowflake at youtube.com/newscientist

This so-called Bergeron-Findeisen process is what we hope to trigger.

The cannon cranks up, jetting out plumes of small, white pellets. In the fog of this snow spray, it is hard to distinguish anything, let alone our hoped-for supercooled cloud. But we manage to swipe a few snow crystals to examine under a microscope. The news isn't encouraging. Despite our best efforts, the tiny, round crystals aren't getting any bigger. The problem is the cannon itself, the group agrees. It produces spherical particles, and without rough edges, it is harder for these crystals to grow.

"Connolly whips out a plastic drinking bottle and a bicycle pump"

So, we are going to have to make ice crystals from scratch. We decide our best chance is to get the air in the chamber down to -38°C, cold enough for homogeneous nucleation, because at higher temperatures, only around 1 in a million aerosol particles will act as a nucleus for an ice crystal. But the chamber itself can only be cooled to -20°C (4°F). How can we make the air even colder?

Connolly whips out a plastic drinks bottle and starts pumping air into it with a bicycle pump. "If we let the air out really quickly, then it has to work to push the air molecules outside of the bottle out of the way," he says. That requires energy – in this case heat – so the escaping gas cools rapidly, lowering the temperature further. We will also need a source of water vapour: a hastily sourced kettle should do the job nicely. And, because the Energy House 2.0 chamber is cavernous, our highly qualified academics rig up a tall, tarpaulin tube in one corner to contain the experiment.

By this point, we have been in the freezing chamber a while, and we are all starting to vibrate with the cold. It is time to put physics to the test. Connolly wriggles into our tube. The kettle is by his feet, boiling furiously, producing plumes of water vapour. We hand him the plastic bottle, and the air pops as the pressure is released. There is a tense, silent wait. Then Connolly exclaims – with more than a hint of relief – that there are a few snowflakes swirling about him. He catches one on a glass slide and posts it out through a gap in the tarpaulin.

The flake is tiny, but size has ceased to matter. We rush to the microscope and inspect our creation. Sure enough, a crystalline structure glimmers into focus, delicate tendrils reaching towards the lens. "It doesn't look like a single ice crystal," says McFiggans, peering at it. He thinks we have caught a bundle of ice crystals that have joined together in their fall through the chamber. "We've grown a snowflake," he says. A round of applause clatters through the chamber.

Our snowflake is less than 2 millimetres in size, not even close to rivalling Libbrecht's snow crystal, let alone Coleman's milk-pan-sized flakes. But I'm not counting this as a failure. Discovering just how complex it is to form a single snow crystal has left me with a newfound appreciation for the magic of those dancing white flecks. I will never look at a snowflake the same way again. ▮

Madeleine Cuff is by far the coolest reporter at *New Scientist*

It's a dog's (inner) life

What is actually going on inside a dog's head? **Thomas Lewton** investigates with a little help from his trusty companion, Laika

"CHICKEN. Chicken. Chicken." I'm woken by the sound of my own voice looping madly. My sleep-addled mind can't work out what's going on. What time is it? Am I still dreaming? Then Laika, my dog, bounds into my bedroom.

Laika is a good dog, or at least I thought she was. I recently bought a touchpad called FluentPet, which allows you to record your own voice onto an array of buttons so that pets can push them and "speak" words. Laika can ask me to fill her water bowl, go to the park or scratch her belly. The trouble is, the whole thing has backfired and she has started asking for treats at all hours. That has made me wonder just how far her mental abilities go. Is her doggy mind really clever enough to guilt-trip me into giving snacks? Come to think of it, does she know what a snack is?

Most dog owners, like me, have wondered about these deep questions, and we will probably never get fully satisfying answers. But thoughtful experiments and emerging technologies are starting to provide a clearer picture of the canine mind. So, with Laika at my side (and a pocketful of treats), I set out to discover what dogs really have going on between their fluffy ears.

On one level, it is surprising that dogs and humans can communicate at all. Our two species separated on the evolutionary tree roughly 95 million years ago, and our last common ancestor had a brain smaller than that of a mouse. This means humans and dogs found their own distinct paths to their large brains, and consequently there are myriad differences between them, says evolutionary neuroscientist Erin Hecht at Harvard University. Clearly, though, dogs and humans can understand each other to some extent. This can probably be partly explained by two things. First, dogs evolved from wolves, which traditionally live in large family packs. "Wolves have all these behavioural traits to organise a family, so that gives dogs the ability to join a family, which in this case is human," says Ádám Miklósi at Eötvös Loránd University in Hungary, who directs the Family Dog Project, a long-running research endeavour. Second, dogs have lived alongside humans for millennia, which has created selection pressures for dogs that are better able to communicate with humans. "They can let us know what they want and they can understand, to some extent, what we're saying to them – so that's probably produced changes in their brain," says Hecht. We know, for example, that dogs have brain regions that respond strongly to human vocalisations like laughing and crying.

But it is all too easy to project meaning onto these interactions that isn't there. Social media is awash with videos in which dogs appear to combine words into sentences on touchpads.

SPENCER WILSON

In one, a dog called Bunny pushes buttons to say "mad", "ouch", "stranger", "paw"; at which point his owner finds a splinter-like object between his toes. Other dogs use the pads to express emotions like disgust, love and joy. It is fair to say all this is far beyond Laika's abilities, and I can't help doubting how much these other dogs really know what they are saying. "You're getting into very dangerous waters here," says Miklósi, who says he is "pessimistic" about such claims.

That said, recent research suggests dogs do have some understanding of what words mean. In August, Federico Rossano at the University of California, San Diego, and his colleagues found that dogs trained to use soundboards responded appropriately to words like "outside", regardless of whether these were said by their owner or a stranger or spoken live or from a recording. This suggests that the dogs weren't reading their owner's body language or randomly pressing buttons in the hope of something nice happening, but that they do associate some specific context with the button, says canine psychologist Juliane Kaminski at the University of Portsmouth, UK.

Often, behaviours like these can be explained by association, with dogs learning to read our actions and make predictions about what will happen. Based on subtle gestures, your dog can know that you are about to go on a walk, perhaps before you are even consciously aware of it, says Miklósi. But that is distinct from dogs having a clear mental representation of what a "walk" is. When dogs press buttons, "it doesn't demonstrate that the dogs have an expectation that it changes the owner's mind", says Kaminiski.

All of which makes me less concerned that Laika is manipulating me – but I have begun to worry whether she even knows I exist. In an effort to find out, I put Laika on her lead and take the train to visit Kaminski at her Dog Cognition Centre in Portsmouth. There, along with her PhD student Amy West, she has been testing the extent to which dogs understand others' thoughts, an ability referred to as "theory of mind".

For her first test, Laika sits in front of two open boxes with treats inside. The Dog Cognition Centre has sourced the "smelliest sausages", says West, to really motivate Laika. The box on the left is opaque, except for the front panel, which allows her to see inside. The second box is transparent. With Laika waiting expectantly, I enter and stand on the opposite side of the room, so that I can't see the treat in the opaque box, but can see the one in the transparent box. If Laika is aware of what I ›

can see, then she is more likely to stare at the treat in the transparent box, anticipating that I will pick that one up and give it to her. "We are asking if she makes the inference that your behaviour is based on what you can and cannot see," says Kaminski. Laika looks at neither treat but simply gazes at me, which doesn't exactly instil me with confidence about the richness of her inner world. For context, human infants reach the level of theory of mind required for this test at around 12 months.

Still, we press on to the next test, named "chimpanzee chess" because it is more often used to test the cognitive abilities of primates. It involves me competing with Laika for pieces of sausage hidden under flowerpots, some of which I sneakily remove. If Laika guesses which piece of sausage remains by choosing the right pot, it indicates she has some awareness of what I have seen in the past. Human children reach this level at around 24 months. Against my expectations, Laika beats me in two consecutive games. Of course, we can't draw conclusions based on these two trials alone. But I'll take it: there may be mental representations in the old dog yet.

More rigorous experiments that applied these kinds of tests to many dogs have found they are sensitive to what a human can and can't see, and there is some evidence that dogs have the level of theory of mind required to play chimpanzee chess. Yet even chimpanzee chess falls short of testing a higher-level theory of mind, which involves the ability to understand that other beings might hold false beliefs about the world. Human children attain this level at roughly the age of 4. "Interestingly, it's also the age when children start lying because they understand there are certain things in the world that you do not have knowledge of, which they can manipulate," says Kaminski. All of this probably means that Laika doesn't have a hugely well-developed mental grasp of who I am and what I know about the world.

Having learned what I can from behaviour studies, I turn to the booming field of canine brain imaging. For years, researchers have been scanning people's brains while they perform mental tasks, and these studies have revealed the patterns of neural activity that underlie everything from recalling memories to conjuring up mental imagery. People are asked to picture an orange, for example, and we then find out the neurons that do that job. More recently, researchers have tried the same techniques on dogs, examining their neural responses to voices, faces and emotions as well as identifying brain regions responsible for language representation, attachment and relationship dynamics with humans.

THOMAS LEWTON

Laika sports an EEG headset made by start-up Dognosis

The difficulty with doggy brain imaging, however, is ground truth. There is no way of getting dogs to picture an orange or even asking them what they are experiencing. A dog might be wagging its tail inside an MRI machine, but we can't know if that actually means it is happy – or even if happiness is a valid emotion to project onto a dog.

However, a start-up in India called Dognosis is making progress by building EEG headsets for dogs that aim to "decipher the canine mind in real time". The idea is to connect dogs' internal neural signatures with outward behaviours in their natural environments. If the dog is wagging its tail while running through a field, we can be more confident of what's going on in its inner world.

Founder Akash Kulgod is currently refining a prototype device using dogs' impressive ability to sniff out cancer samples. He shows me a video in which Dognosis's "canine experimenter in chief" – a beagle called Snow – can roam freely among eight different boxes in a room, one of which contains a mask that someone with cancer has breathed into. When Snow smells this box, it sparks a fairly consistent electrical signature in the EEG headset. In the first instance, this could enable Kulgod to identify when dogs smelled a disease much more reliably. (Dogs are legitimately great at identifying disease, but can start to conveniently sniff it out everywhere after a while, in the hope of getting more treats.) Dognosis is now partnering with hospitals in low-income countries, where biopsies and blood tests for cancer are harder to access than dogs.

"A dog might wag its tail, but we can't truly know if that means it is happy"

This research highlights one of the hardest problems when it comes to knowing what's going on in the minds of dogs. Because of their incredible olfactory abilities, so much of dogs' perception is based on smell. That means there is a huge gulf between the human and dog "umwelt", or sensory experience of the world, says Kulgod. "They're seeing with their nose, quite literally."

So even if there is some kind of mental representation of "chicken" when Laika presses the relevant button on FluentPet, it is probably vastly different from my own. This difference surely extends to how dogs perceive other beings in the world, say Hecht. "What are humans for dogs? Are we another dog? Are we a strange creature? It's very complicated to find out how they [imagine] us," says Miklósi. He welcomes the research possibilities that wearable brain imaging would open, but argues that such technology could get in the way of everyday human-dog relationships. "If you are a dog owner, you don't really need that," he says.

Still, Kulgod says he is confident that technology can "amplify our ability to connect with dogs". He hopes that Dognosis's headset will, at some point, be able to find consistent neural signatures of mental states, so the device can tell you when a dog is experiencing anxiety, say. And now Laika and I are helping with the effort. Kulgod sent me one of his headsets and Laika (pictured above) looks fantastic in it. I've been recording her brainwaves as I say her name to see what's going on in her mind. But let's face it: she's probably just thinking about chicken. ▮

Thomas Lewton barks once for yes, twice for no and three times for a cookie

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Biscuit bliss

Chemist and *The Great British Bake Off* finalist **Josh Smalley** shares the secrets that will help you create a lip-smackingly good gingerbread Christmas tree

IT WOULDN'T be Christmas without the smell of freshly baked gingerbread wafting through the house. With a blend of warming spices and rich molasses, it is a must-have treat for a winter's day. And as a child, it was always gingerbread that I would leave out for Santa each Christmas eve. In fact, I think gingerbread might be my favourite biscuit – providing it has that perfect balance of crunch and chew.

I like to think I know a thing or two about how to achieve that. I competed in the 2023 series of the *The Great British Bake Off* and made it to the final – and I even received that famously hard-to-obtain handshake from judge Paul Hollywood during biscuit week.

My success is down to the careful application of science to the craft of baking. So allow me to share with you a handful of key insights you need to bake a really show-stopping gingerbread – and the science behind why they are so crucial. Since I am a chemist by trade, we will be eschewing the traditional gingerbread house and instead assembling our biscuits into a freestanding Christmas "chemistree". My mouth is watering already.

As with all biscuits, the first step is to prepare our dry ingredients. We need flour, sugar, spices and bicarbonate of soda (see "Ingredients and method", right), each with important roles to play. The flour serves as a binding agent and helps form the structure of our biscuit, while the sugar will caramelise for sweetness, colour and texture.

The flavour of gingerbread comes from the blend of spices, with ginger and cinnamon leading the way. Their pungent fragrance is the result of volatile organic, or carbon-based, molecules, which rise into the nose and activate our olfactory receptors. Flavour compounds in ginger include gingerol and zingiberene, with cinnamaldehyde central to the aroma of cinnamon. They are all individually wonderful, but the magic of gingerbread stems from how these molecules come together. In the heat of the oven, these flavour molecules are also chemically transformed to become even more appetising, as we will see.

My first key tip, though, is to always add sodium bicarbonate (sometimes called bicarbonate of soda or baking soda) to a gingerbread mix, as it will result in a more aerated structure. Sometimes, gingerbread can be tooth-breakingly hard – not something I personally enjoy. But sodium bicarbonate helps avoid that. With the chemical formula $NaHCO_3$, it undergoes a decomposition reaction in the heat of the oven, producing sodium carbonate (Na_2CO_3), water vapour and carbon dioxide. Both carbon dioxide and water can also be formed in an acid-base neutralisation reaction, since sodium bicarbonate is alkaline and will react with any acids, such as those found in brown sugar – yes, brown sugar is mildly acidic! The bubbles of gas help leaven the biscuit, giving a gingerbread that is light but has a perfect snap.

We can now begin to bring our gingerbread dough together with the addition of the wet ingredients. My second top tip is that you want just a weak network of gluten in your dough to ensure the right texture – but let's unpack that.

"Royal icing is a great glue for sticking your gingerbread together"

Ingredients and method

For the gingerbread:

- 275 g (2¼ cups) plain flour
- 1.5 tsp ground ginger
- 1.5 tsp ground cinnamon
- 1 tsp mixed spice (or pumpkin pie spice)
- 1 tsp bicarbonate of soda (baking soda)
- 100 g (7 tbsp) unsalted butter
- 50 g (¼ cup) caster or granulated sugar
- 50 g (¼ cup) light brown sugar
- 1 medium egg
- 60 g (4 tbsp) golden syrup (or light molasses)
- 60 g (4 tbsp) black treacle (or dark molasses)

For the icing:

- 200 g (1⅔ cups) icing or powdered sugar
- 20 g (1.5 tbsp) pasteurised egg white (or meringue powder)
- 1–2 tsp lemon juice, if desired
- Food colourings, if desired

Science of baking

Watch a step-by-step guide to making the perfect gingerbread at youtube.com/newscientist

During this stage, two flour proteins called gliadin and glutenin become hydrated and interact to form the protein complex we know as gluten. The more a dough is worked, the stronger this gluten network becomes, which, depending on the type of bake you are making, could be desirable or not. When making bread, we add copious amounts of liquid at the start and knead rigorously to develop an elastic gluten matrix, leading to a soft and springy loaf. For our gingerbread biscuits, however, we want to reduce that gluten build-up. So, always rub the butter into the flour mix before adding any liquid. Doing this coats the gliadin and glutenin in a layer of fat so that when the liquid ingredients are added, these proteins aren't hydrated as easily. We do need some gluten, as it helps capture the air bubbles described earlier. But just knead the dough a little by hand – no electric mixers, please – so you have enough gluten but not too much.

Now for tip number three, which I strongly suggest you don't skip: allow the dough to rest in the fridge. This pause gives the proteins the opportunity to absorb more moisture and gives the gluten network a chance to relax, such that the dough doesn't shrink back when rolled out. Even more importantly, it firms up the dough to avoid the biscuits spreading in the oven. Because we are looking to create well-defined shapes from our gingerbread, this chilling stage, both before rolling out and again before entering the oven, is essential.

DAVID STOCK

One part of Josh's gingerbread tree, complete with isomalt window. Scrumptious!

After cutting out your gingerbread – head to newscientist.com/gingerbreadtree for some handy templates – it's time to bake. Always arrange the biscuits on a metal baking sheet, since metal conducts heat efficiently and gives your biscuits a crisp underside. Plus, you want them to have a strong colour before you take them out of the oven to cool, as this will ensure a depth of flavour and a biscuit that sets dry and strong – the ideal material for a chemistree.

As I hinted earlier, during the bake, some of the flavours in gingerbread are changed, with the gingerol being converted into other compounds via various chemical reactions. A reverse aldol reaction transforms it into zingerone, while dehydration reactions can turn it into a class of compounds called shogaols. In the 1970s, researchers determined that shogaols are about twice as pungent as gingerol.

The last step – and my favourite part – is to decorate your chemistree. The biscuits can be simply decorated with glacé icing, comprising icing sugar and water. Or try another scientific tip: use royal icing, which is made with the addition of egg white. The network of proteins from the albumin in egg whites provides added structure and stability for royal icing, allowing it to be piped onto biscuits with ease and to harden quickly. This makes it a great glue for sticking gingerbread panels together – otherwise you run the risk of your tree disintegrating. For a really vibrant finish, you could also divide your icing between a few small bowls and use add different food colourings.

I have just one more show-stopping suggestion for you. If you want to go the extra mile and produce a really exceptional gingerbread tree, you could make some baubles out of isomalt. This sugar substitute can be melted and poured into a gap in the biscuit and left to set into a transparent "window". Isomalt is derived from regular sugar (sucrose) via an enzyme-catalysed rearrangement reaction to isomaltulose followed by a hydrogenation reaction. It is much less prone to crystallising than regular sugar and better resists humidity, giving it unique properties that are perfect for creating transparent, glass-like decorations.

Right, now get to the kitchen! You have all the chemistry know-how you need to make a seriously impressive gingerbread creation. You don't have to stick to a tree – let your imagination run wild and show me what you make on X using the hashtag #chemistree. I can't wait to see how you get on. ▮

Josh Smalley never has a soggy bottom

1. Sieve the flour, spices and bicarbonate of soda in a bowl.

2. Rub the butter into the flour mix using your fingertips, then stir in the sugars.

3. Add the egg, golden syrup and treacle to the bowl, then mix everything together using a spatula to form a dough.

4. Turn the dough out onto a floured work surface and knead lightly until smooth. Flatten the dough, wrap in cling film and put in the fridge for 30 minutes.

5. Roll out the gingerbread on a lightly floured surface to a 6-millimetre (¼-inch) thickness, with a piece of cling film on top of the dough to ensure a smooth surface. Remove the cling film, then cut out the shapes of the gingerbread (you can find a template at newscientist.com/gingerbreadtree if you would like to use ours). Place the cut-outs on a baking sheet lined with parchment paper and chill in the fridge for 30 minutes. Meanwhile, preheat the oven to gas mark 4, or 180°C (350°F), or 160°C (320°F) for convection ovens.

6. Bake gingerbread biscuits in the oven for 14 to 16 minutes or until deep golden brown, then transfer to a wire rack to cool.

7. To make the royal icing, add the icing sugar, egg white and 1 tsp lemon juice to the bowl of a stand mixer and beat until smooth. Add additional lemon juice a few drops at a time until a suitable piping consistency is reached and colour the icing as you like using the food colourings.

8. Decorate your chemistree.

The back pages

Quiz of the year
Find out how much attention you paid to the news in 2024 p74

Puzzles
Can you solve our holiday cryptic crossword? p76

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Complete our logic puzzle and reveal a festive treat p77

Feedback
Bah humbug for the NORAD Santa tracker p80

Twisteddoodles for *New Scientist*
Picturing the lighter side of life p80

Dear David

Goodwill hunting

In many households, Christmas can be tense. Can psychology help us avoid those festive arguments, asks **David Robson**

David Robson is an award-winning science writer and author of *The Laws of Connection: 13 social strategies that will transform your life*

Further reading

If you are struggling to cope through the holiday season, the mental health charity Mind has a host of useful advice: mind.org.uk/information-support/tips-for-everyday-living/christmas-and-mental-health/christmas-coping-tips/

Dear David appears monthly

Next week

Stargazing at home

AS THE end of 2024 approaches, I would like to say a big thank you to everyone who has shared their dilemmas with me over the past year. For my festive column, let us address a nearly universal complaint: holiday arguments.

It should be no surprise that feelings run high over the holiday season. We may hope to spend the day bonding over our shared past, but life is more complicated than a Christmas movie, as old resentments bubble under the surface. Soak everyone in alcohol and it takes just one small spark to set the whole gathering alight with accusations and recriminations.

If this sounds familiar, then I have a technique that might help you lower the temperature at the tensest moments. It stems from the fact that many arguments escalate through threats to our self-integrity – the concept of ourselves as good, moral and successful people. A family member's jibe leads us to feel that our very identity is crumbling, and we react with avoidance, descending into a sulky silence, or attack – by lashing out in kind. This is likely to provoke further criticism, of course, as we find ourselves picking over past offences anew.

The solution, according to psychological science, is "self-affirmation". Not to be confused with manifesting or mantras, this evidence-backed strategy involves writing down five to 10 of your own qualities and values that are most important – things like independence, humour, creativity or a work ethic. You then take your number one choice and spend a few more minutes reflecting on why it is so central to your life.

SHUTTERSTOCK/VICTORIA 1

The aim is to promote a stronger and more expansive sense of who we are, so that small slights no longer pack the same punch. At the very least, we should feel any criticisms less keenly, so that we don't spend the rest of the day picking over the perceived insult. At best, we may find it in ourselves to feel more love and connection to our aggressor, and we may even come to accept their view. Karina Schumann at the University of Pittsburgh in Pennsylvania has found that self-affirmation can improve the quality of people's apologies, for instance.

You may choose to self-affirm at the start of the day, to gird yourself for what follows, or apply the technique as you cool down after a disagreement – whenever suits you best.

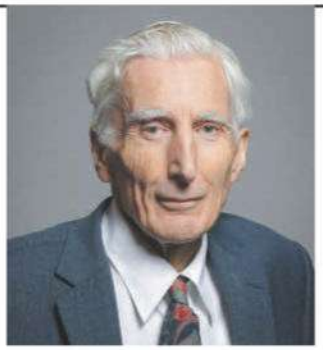
If you find that it helps you through your family reunion, you might aim to make it a habit throughout the New Year. A paper published in August reported that people who spontaneously self-affirm during times of conflict enjoy greater satisfaction, commitment and intimacy with their long-term partners, compared with those who don't.

What better way is there to end one year, and begin a new one, than strengthening relationships with the people you love? ▮

These articles are posted each week at newscientist.com/maker

RSA

From mapping the mysteries of black holes to shaping international science policy, Sir Martin Rees, Lord Rees of Ludlow, is a renowned British astrophysicist and cosmologist.



First joining as an RSA Fellow forty years ago, Sir Martin is best known for his pioneering work in galaxy formation and the structure of the universe. Having served as the Astronomer Royal, President of the Royal Society and currently a member of the House of Lords, we asked Sir Martin to share why the RSA Fellowship remains close to his heart and continues to inspire him.

Why are building connections important?

Curious about the power of professional networking in the science world, we asked Sir Martin Rees for his view. He emphasised the importance of establishing new connections as being "very important at all levels." He stressed the incredible value of building new friendships through professional societies and thought-provoking events like RSA's lectures and gatherings.

Championing diversity

From Sir Martin's perspective, the RSA Fellowship can cater to a wide range of individuals: "The Fellowship is very varied. I can imagine it is especially valuable for retired academics who are living in the country", he explained. For Sir Martin, living in Cambridge gives him the advantage of constant academic interaction. He acknowledged how, for those "retired to some small town where there is no immediate contact with people in their field", the RSA's community provides an invaluable opportunity for engagement. He went on to highlight how those in more remote locations "benefit hugely from these networks locally like Zoom" or, in person.

The RSA provides an enriching space for individuals to share ideas, grow professionally, and make long-lasting positive impact. As Sir Martin's experience shows, the Fellowship truly embodies a diverse, supportive, and forward-thinking community that benefits people at all stages of their lives.

The RSA Fellowship is open to everyone over the age of 18, and we actively welcome new voices and perspectives. We believe in building a diverse and dynamic community, so if you're interested in joining, the application process is straightforward and accessible to all.

Join our Fellowship today and connect with Fellows like Martin for just £4 per week.

USE DISCOUNT CODE NS10 TO RECEIVE A 10% DISCOUNT

New Scientist Events

Instant Expert

Inside the subatomic universe

Saturday 18 January 2025 | 10am - 5pm
Congress Centre, London

Join six leading experts to find out everything we know about the subatomic world. Take a deep dive into the building blocks of the universe, from the atom to the standard model, and learn how cutting-edge particle accelerators are uncovering the mysteries of mass, quarks, neutrinos and beyond.

- Learn about the standard model of particle physics and why it's only the beginning
- Uncover the incredible results from particle colliders such as the LHC at CERN
- Discover neutrinos, the strangest particles in the universe
- Find out why matter has mass
- Explore why there's more matter than antimatter in the universe

EARLY BIRD DISCOUNT CLOSES 22 DEC

Find out more at
newscientist.com/subatomicuniverse

Testing times

From a fish with a tiny brain to the world's oldest cheese, we have reported on plenty of strange and unusual science discoveries this year. Challenge yourself and see what you can remember in this fiendish set of questions from our quizmaster **Bethan Ackerley**

1 Kicking off the year, researchers revealed back in January that they had successfully created a strange and notoriously difficult-to-make material – what is it known as?
A Painter's problem
B Joiner's dilemma
C Plumber's nightmare
D Builder's headache

2 In February, we learned that if you want a large language model to get better at maths, you should tell it to pretend to be whom?
A Alan Turing
B The US president
C A vampire
D A *Star Trek* captain

3 Researchers have developed a spacesuit that lets astronauts drink their own recycled urine, as we reported in July. But what is the diaper that NASA astronauts currently wear during launch and spacewalks called?
A The Fecal and Urine Containment Device
B The Maximum Absorbency Garment
C The Disposable Containment Gear
D The Take-off Trunks

4 In February, we learned about *Danionella cerebrum*, a tiny fish that has the smallest brain of any known vertebrate. But what else makes it special?
A It's extremely loud
B It lives forever
C It farms plankton
D It has no heart

5 What thickness of paper is most likely to give you a paper cut, as we reported in June?
A 40 micrometres
B 65 micrometres
C 90 micrometres
D 115 micrometres

6 In September, the world's oldest cheese was revealed – but in what unusual location was it found?
A Near the summit of Mount Everest
B On mummified bodies
C In a bank vault
D At the bottom of Lake Windermere

7 In March, researchers identified an unusual avian gesture – what were the Japanese tits in question saying?
A "OK"
B "Nice job"
C "After you"
D "Cheque please"

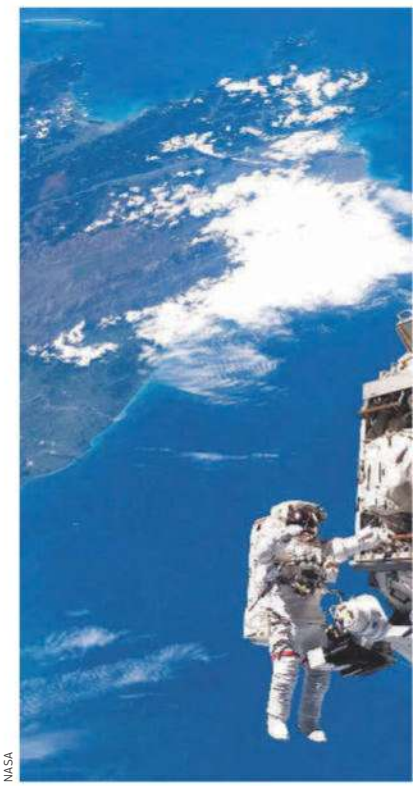
8 In which city was the earliest evidence of cocaine use in Europe found, as we reported in August? (Hint: last year, this city provided us with the first signs of cannabis in archaeological skeletal remains.)
A Seville, Spain
B Berlin, Germany
C Milan, Italy
D Vienna, Austria

9 In February, we reported on which unusual new use for wasabi?
A As a local anaesthetic
B To boost photosynthesis in plants
C To extract gold from computer motherboards
D To disinfect ancient papyri

10 What method has the dyeing poison frog been employing to flush out unsuspecting prey, as we learned in February?
A Auto-cannibalism
B Tap-dancing
C Home brewing
D Yodelling

11 Speaking of frogs, we've published plenty of news about our amphibian friends this year – but which of the following haven't we reported on in 2024?
A Lungless frogs turned out to have lungs
B Charles Darwin's frogs have been mating upside down
C Endangered frogs have fought off disease using saunas
D Northern pool frogs have dandruff

12 What simple trick will get a dog to warm up to strangers, as we learned in February? (Note: Please use *New Scientist*'s dog-luring advice responsibly.)
A Follow it for 15 minutes
B Make your hands cold
C Rub fennel on yourself
D Sing in a deep voice



NASA

ZOONAR GMBH/ALAMY

13 In February, what ancient object provided researchers with possible hints of the precursor to the Basque language?
A A bronze hand
B A wooden funerary mask
C A woollen wig
D A bone flute

14 Which of these foodstuffs was made in space for the first time, as reported in February?
A Miso paste
B Marmite
C Balsamic vinegar
D Baker's yeast

SHUTTERSTOCK/LIV FRIIS-LARSEN

This year saw the discovery of an unusual new use for wasabi, pictured here

JAROMIR CHALABALA/ALAMY

CCBI/FLATIRON INSTITUTE/SKELLYSIM

Clockwise from far left: astronauts on a spacewalk (no information available on their toilet facilities); a dog – but how best to approach it?; a fruit fly cell; a family playing *Pong* in 1977, long before scientists got involved this year; how English are these place names?; and some Italian cheese, but probably not the world's oldest

GRAHAM PRENTICE/ALAMY

INTERFOTO/ALAMY

15 Stink bugs were shown to be keen horticulturalists earlier this year – but what is special about their gardens?
A They glow in the dark
B They are on their legs
C They photosynthesise at night
D They accumulate nickel

16 Jacob and Tibu are brothers who achieved an extraordinary feat in February. What was it?
A Becoming the oldest living identical twins
B Being the first birds to be cloned
C Making the longest recorded swim by African lions
D Becoming the first twins on the International Space Station

17 What did scientists get to play the computer game *Pong*, as revealed back in August?
A A glob of jelly
B Heart cells in a Petri dish
C A leech
D A herd of cows

18 In October, we learned that your brain has individual neurons that respond to the smell of what?
A Pine trees
B Stagnant water
C Bananas
D Rosemary

19 In August, we reported on the largest genome to be sequenced so far – of which organism?
A The fork fern
B The South American lungfish
C Przewalski's horse
D The shiitake mushroom

20 What unusual phenomenon was observed inside fruit fly egg cells, as revealed in February?
A Quantum tunnelling
B The formation of ice
C Radioactivity
D Miniature tornadoes

21 In October, researchers identified potential signs of breast cancer in a woman in which painting?
A *Bathsheba at Her Bath* by Rembrandt
B *Sacred and Profane Love* by Titian
C *The Flood* by Michelangelo
D *Adam and Eve* by Lucas Cranach the Elder

22 Macaques can be trained to tap to the beat of music, as we learned in May. Which of the following songs did researchers test them on?
A *Everybody (Backstreet's Back)* by Backstreet Boys
B *Run Away With Me* by Carly Rae Jepsen
C *Hot Stuff* by Donna Summer
D *Tiny Dancer* by Elton John

23 What is unusual about a skeleton in an ancient Roman grave that we reported on in October?
A It's a dog
B Its bones have turned purple
C It's made of the bones of several people
D It has gemstones in its skull

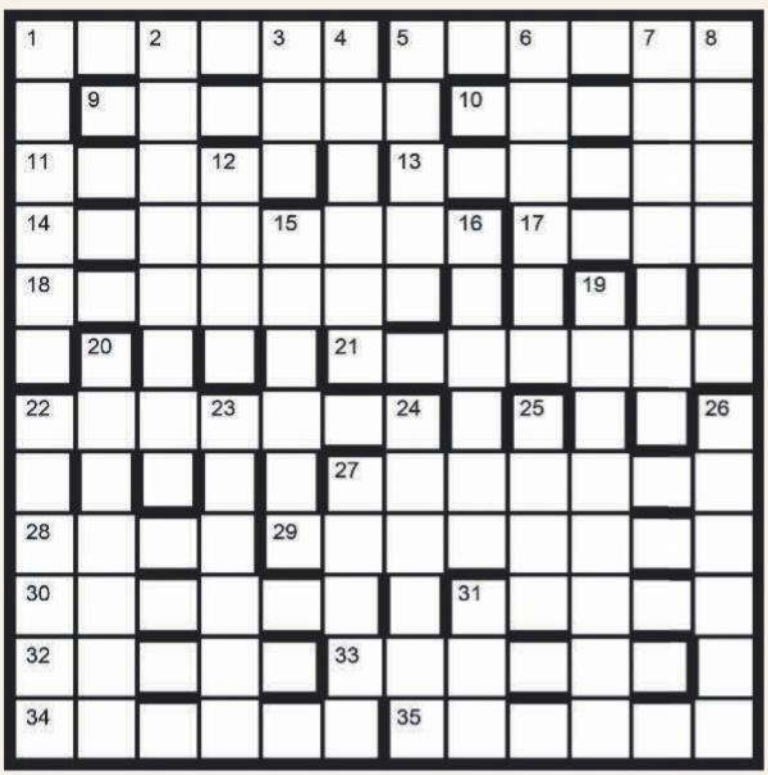
24 When it wasn't busy improving the taste of beer or identifying entertaining chess moves, artificial intelligence has been uncovering the origins of English place names, as we reported in January. But which place had the most archetypically English name?
A Toddington
B Harlington
C Lowthorpe
D Belgravia

25 And finally, to cheat the second law of thermodynamics 95 per cent of the time, what do you need, according to research out in July?
A A red squirrel
B A Mobius strip
C A single-electron bond
D A microscopic diving board

Answers on page 78

Cryptic crossword #151: Collider *Set by Rasa*

It's holiday time at the particle physics lab! Before the festivities can begin, though, we need to run a few more experiments. Watch for collisions and analyse the pattern to get one letter per column. Write them in the squares below the crossword to reveal who are exchanging gifts this year.



For a guide on how to solve *New Scientist*'s cryptic crossword visit: newscientist.com/cryptic

ACROSS

1 Problem involving pet cuckoo cartilage (6)
5 For the audience, expensively decorates clubs (6)
9 Proust novel stunned state (6)
10 Significant other claims copyright on music in a movie (5)
11 Horse managers discussed rules (5)
13 Arnie's freshened up (6)
14 Release census edited with AI (8)
17 Fantasy creatures start escaping circus enclosures (4)
18 Advertise innovative motor in couple of periodicals (7)
21 Less anxious oracle gobbles plump bird, having dropped weight (7)
22 I retain complicated physics topic (7)
27 Climbing rodent spoiled retreat (4,3)
28 Feel sorry for Yankee pursuing quarry (4)
29 Tibetan monk and leader of Nepal converse endlessly somewhere in Spain (2,6)
30 Group wears revolutionary dress (6)
31 Savour contents of menu, then send back breakfast drink and fork (5)
32 Scottish bodies renovate school, losing one globe (5)
33 Transparent, droopy handle (6)
34 Soften a melon bearing hard coating (6)
35 Sci-fi planet is extremely uncongenial place to go after victory (6)

DOWN

1 Band, soprano and tenor ready to eat (6)
2 Captive boy nabbed by nosy person (8)
3 They deliver uranium, incidentally (3)
4 Presents sumo wrestling around middle of winter (6)
5 Charm a little girl at track event (5)
6 Spike heard two-wheeler after commencement (6)
7 Stewed, like some necks? (7)
8 Snores scrambled security system feature (6)
12 Young dog eats half of my shoe (4)
15 Raise rents south of a medium-sized brewery (6)
16 In the US, crop each eyepiece? (6)
19 Unruly, stylish following managed a retrospective (8)
20 One slip ruined Greek character (7)
22 Lance, I'm in need of bronzer or blush (6)
23 Reach him on vacation to contain YouTube stresses occurring regularly (6)
24 Impart new place for a crutch (6)
25 Logician reading through given names (4)
26 Wax stick beginning to colour fabric (6)
27 Spread the word about vitamin that supports immunity (1-4)
31 Bird edging away from ring-tailed primate (3)

Our crosswords are now solvable online
newscientist.com/crosswords

Answers and our next quick crossword in the next issue

BrainTwister

#50 Puzzle-by-numbers

set by Matthew Scroggs and TD Dang

Solve these six puzzles, then find each region of the image below that contains one of the answers and colour it brown. Each answer may appear more than once.

1. Holly added up the first four odd numbers. What total did she get?

2. Holly added up the first m odd numbers to get a total of 441. What is m?

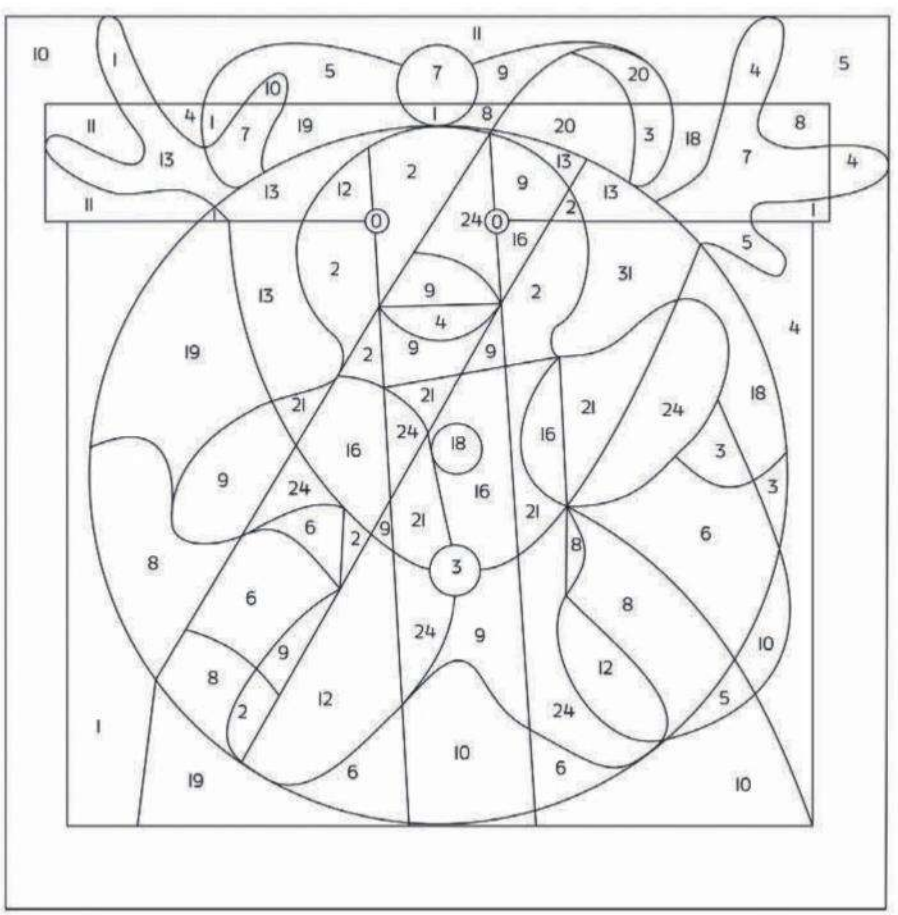
3. The number n! is calculated by multiplying together all the integers from 1 to n. How many zeros does the number 10! end with?

4. How many zeros does the number 50! end with?

5. How many three-digit, positive integers are there whose digits are all 1, 2, 3 or 4, with exactly two digits that are 1s?

6. Ivy works out that there are 72 n-digit positive integers whose digits are all 1, 2, 3 or 4, with exactly n-1 digits that are 1s. What is n?

What Christmassy image have you created?



#51 Ribbon theory

set by Peter Rowlett

I have a large supply of ribbon in lengths of 10 centimetres, 20 cm, 40 cm and 120 cm.

I could make 50 cm of ribbon by using one 40-cm piece and one 10-cm piece. How many other ways can I make 50 cm of ribbon? (Only the combination of lengths, and not the order of the pieces, matters.)

How many ways can I make 80 cm of ribbon?

If I am allowed to cut any one piece of ribbon in half, how many ways are there now to make 80 cm of ribbon?

#52 Tinsel theory

set by Phil Lloyd

Imagine two strands of tinsel tangled together. There are three ways of joining their four ends together in pairs. What is the probability that doing so will create a single, continuous loop?

What if there were three such tinsel strands, or six of them?

Can you find the formula for any number of tinsel strands?

Solutions to all our festive puzzles are on the next page

Quiz of the year
Answers

1 C – Plumber's nightmare
2 D – A *Star Trek* captain
3 B – The Maximum Absorbency Garment
4 A – It's extremely loud
5 B – 65 micrometres
6 B – On mummified bodies
7 C – "After you"
8 C – Milan, Italy
9 D – To disinfect ancient papyri
10 B – Tap-dancing
11 D – Northern pool frogs have dandruff
12 A – Follow it for 15 minutes
13 A – A bronze hand
14 A – Miso paste
15 B – They are on their legs
16 C – Making the longest recorded swim by African lions
17 A – A glob of jelly
18 C – Bananas
19 B – The South American lungfish
20 D – Miniature tornadoes
21 C – *The Flood* by Michelangelo
22 A – *Everybody (Backstreet's Back)* by Backstreet Boys
23 C – It's made of the bones of several people
24 B – Harlington
25 D – A microscopic diving board

How did you do?
18-25 – Excellent work! You have clearly been keeping up with all that is scientific this year, quite possibly via *New Scientist*.

12-17 – Congratulations on a solid display of knowledge about recent research delights across a wide range of fields!

6-11 – This score feels suspiciously like a mixture of luck and educated guesses. Still, hats off for giving it a go.

0-5 – Oh dear. Even pure guesswork should have netted you six or so correct answers. If you don't already subscribe to *New Scientist*, maybe now's the time to do so!

#50 Puzzle-by-numbers
Solution

The answers to the six puzzles are: 1) 16, 2) 21, 3) 2, 4) 12, 5) 9 and 6) 24. Colouring these regions brown will reveal an image of a gingerbread man.

#51 Ribbon theory
Solution

There are three further ways to make 50 cm of ribbon: 5×10 cm, 3×10 cm+1×20 cm and 1×10 cm+2×20 cm. There are nine ways to make 80 cm of ribbon with no cuts: 8×10 cm, 6×10 cm+1×20 cm, 4×10 cm+2×20 cm, 2×10 cm+3×20 cm, 4×20 cm, 4×10 cm +1×40 cm, 2×10 cm+1×20 cm+1×40 cm, 2×20 cm+1×40 cm and 2×40 cm. Cutting a 120-cm piece in half to make a 60-cm piece available adds two new ways to make 80 cm. Cutting a 10-cm piece in half to make two 5-cm pieces adds another six ways. Cutting the 20-cm or 40-cm pieces in half adds nothing, since these sizes are already available. So, there are 17 ways to make 80 cm of ribbon with a single cut.

#52 Tinsel theory
Solution

If one tinsel strand has ends A and B, and the other C and D, then joining A to B (and C to D) gives two loops, but the other two combinations both give one loop. The chance of creating a single loop is therefore 2/3, or about 67 per cent.

With three strands of tinsel and six ends, choosing one will leave five free ends, of which four wouldn't immediately form a short loop. That gives a 4/5 chance of success. There are now four free ends (as above), so the overall chance of forming a single loop is 4/5 × 2/3 = 8/15, or about 53 per cent. Following the same reasoning, with 12 free ends, the chance of forming a single loop is 10/11 × 8/9 × 6/7 × 8/15 = 3840/10,395, or about 37 per cent.

The general formula for n tinsel strands is given by multiplying together (2n-2), (2n-4), (2n-6) and so on until one of the bracketed terms equals 2, then dividing by the corresponding odd terms starting from (2n-1):

$$\frac{(2n-2)\,(2n-4)\times\cdots\times 2}{(2n-1)\,(2n-3)\times\cdots\times 3}$$

Cryptic crossword #150
(set on 7 December)

Answers

ACROSS 1 Stitch, **4** Palate, **9** Half-wit, **10** Niece, **11** Stool, **12** Malware, **13** Hippocrates, **18** Optimal, **20** Ozone, **22** Lagan, **23** Compost, **24** Darnel, **25** Walrus

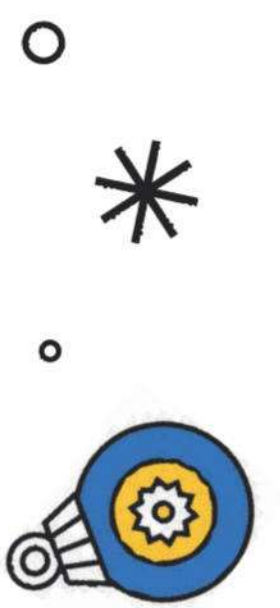
DOWN 1 Schist, **2** Igloo, **3** Cowslip, **5** Annal, **6** Acetate, **7** Eleven, **8** Atomic clock, **14** Integer, **15** Anosmia, **16** Howled, **17** Testes, **19** Mange, **21** Odour

#49 Squares and cubes
(set on 7 December)

Solution

The pair of numbers is 6 and 10. The difference in their squares, 10×10 – 6×6, is 64, which is 4^3. The difference in their cubes, 10×10×10 – 6×6×6, is 784, which is 28^2.

If this pair of numbers is multiplied by a number that is both a perfect square and a perfect cube, the resulting pair of numbers will have the same property. Any number raised to the power of 6 is both a perfect square and a perfect cube, as $x^6 = (x^3)^2 = (x^2)^3$. The smallest such number is 2^6 or 64, so (6, 10) multiplied by 64 becomes (384, 640), which has the same property.



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Early Christmas

It's the holidays, or rather it's not, because, owing to the way print schedules work, Feedback is writing this festive edition in the first week of December. We have ordered presents for Mrs Feedback, we still haven't figured out what Feedback Jr is going to get Mrs Feedback (with Feedback's money), we have put up precisely zero decorations and we are staring down the barrel of multiple school events in which we will be required to feign festiveness for the sake of the children. In short, Feedback is feeling grinchy.

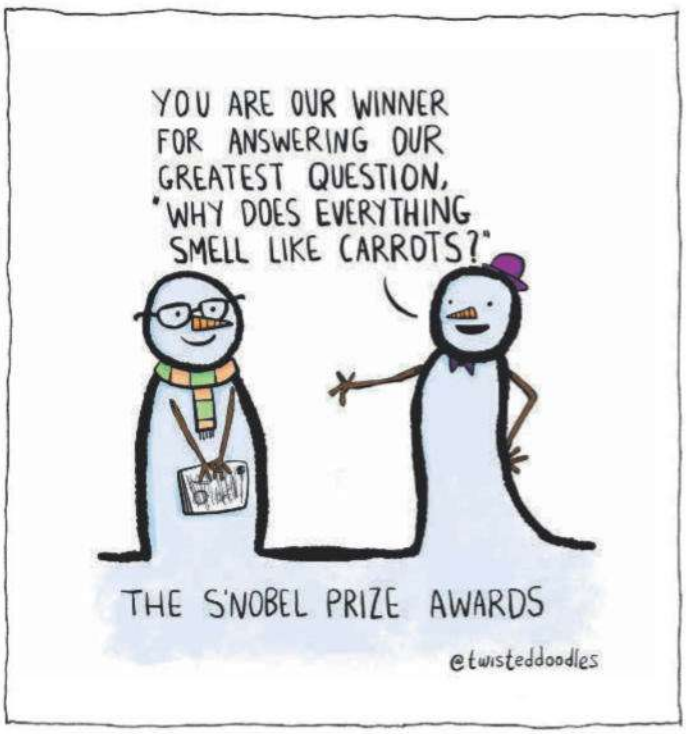
So this seems like a good time to grumble about NORAD Tracks Santa, one of those initiatives that Feedback cannot quite believe exists. NORAD is, of course, the North American Aerospace Defense Command, whose main job is to use a combination of satellites and radar to detect anything flying into North American airspace, like stray Chinese weather balloons. But on 24 December, it conducts an elaborate exercise, run by volunteers, in which it tracks Santa on his journey around the globe. You can ring a number for updates, you can watch his progress on a website and you can even follow along on social media.

Quite how this tradition began is interestingly knotty. A factsheet on the NORAD website tells a heartwarming story: "NORAD has been tracking Santa since 1955 when a young child accidently dialed the unlisted phone number of the Continental Air Defense Command (CONAD) [the precursor to NORAD] Operations Center... believing she was calling Santa Claus after seeing a promotion in a local newspaper. Air Force Colonel Harry Shoup, the commander on duty that night, was quick to realize a mistake had been made, and assured the youngster that CONAD would guarantee Santa a safe journey from the North Pole."

But is this story true? This is hard to fully unravel. Details differ between accounts, from how Shoup initially responded, to how many calls came in that first year. What is clear, though, is that this all started at the height of the cold war. NORAD is there to detect incoming nuclear missiles, so it is inherently scary: its headquarters is literally a bunker dug into a mountain. A stunt where it tracks Santa was, and is, a brilliant way to make it seem cuddly. On the one hand, if a nuclear war starts, NORAD will almost certainly play an instrumental role in it; on the other, it does do the cute Santa tracker.

However, Feedback's biggest gripe with the whole thing is that we are 90 per cent sure the stunt was the inspiration for the new Christmas-themed fantasy-action-comedy-thriller *Red One*. In this stacked modifier of a film, Santa's journey is reimagined as a militaristic security operation involving fighter jet escorts and a sort of North Pole Secret Service – spearheaded by Dwayne Johnson. It looks like one of the worst films of the year and Feedback strongly suspects that NORAD Tracks Santa is ultimately to blame.

Twisteddoodles *for New Scientist*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Long-winded set-up

Speaking of tracking immaterial things, an Australian research project is asking people to monitor their own flatulence. It is called, inevitably, Chart Your Fart.

Using a free phone app, participants "will track the quantity and quality of their outputs, including attributes such as stench, loudness, duration, linger and detectability". Feedback appreciates the precision-guided use of the word "linger", and notes that a fart's linger can be scored from "fleeting" to "perpetual".

The aim is to understand more about "one of the leading gut health symptoms experienced by Australians", specifically "excessive flatulence", which up to 43 per cent of Australians report experiencing most days.

Feedback cannot endorse *The Guardian*'s headline about the project, "Wind power". We also cannot approve of the decision to restrict the study to Australia. Thankfully, however, others are on the case, as shown by our startling feature on page 42 about the researchers trying to catch farts. And their work is of vital importance at this time of year: in many countries, millions of us are about to eat terrifying quantities of meats, mince pies and, most gaseously of all, Brussels sprouts.

Cheap at the price

Readers who still don't have a present for their loved ones: bad luck, you missed a golden opportunity. The auction house Christie's, in London, recently had its first-ever science fiction and fantasy auction, with the stated highlight being the *Dune* Bible: a collection from around 1975 of behind-the-scenes documents from Alejandro Jodorowsky's unproduced film adaptation of Frank Herbert's book *Dune*. This is an ideal excuse for Feedback to get something off our chest, so here we go.

Jodorowsky's *Dune* has taken on an almost mythic status: one of the great what-ifs of sci-fi cinema. An epic planned to be at least 10 hours long, starring Orson Welles and Mick Jagger, with production design from H. R. Giger (later of *Alien* fame). If only he had managed to make it, it would have been a classic.

Here's the thing. Jodorowsky is one of the most pretentious film-makers ever to write a screenplay containing a description of his own penis. Feedback learned this from Danny Peary's *Cult Movies*, which covers Jodorowsky's mystical 1970 western *El Topo*. Peary complains of "far too many references, Jungian and religious symbols / artifacts ... in-jokes, and too much obscure imagery for anyone but Jodorowsky to know what is going on". Imagine that for 10+ hours. We were spared.

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